UNIVERSIDADE DA BEIRA INTERIOR
Engenharia

Manufacturing Techniques of a Hybrid Airship Prototype

Sara Emília Cruz Claro

Dissertação para obtenção do Grau de Mestre em
Engenharia Aeronáutica
(Ciclo de estudos integrado)

Orientador: Prof. Doutor Jorge Miguel Reis Silva, PhD
Co-orientador: Prof. Doutor Pedro Vieira Gamboa, PhD

Covilhã, outubro de 2015

AVISO

A presente dissertação foi realizada no âmbito de um projeto de investigação desenvolvido em colaboração entre o Instituto Superior Técnico e a Universidade da Beira Interior e designado genericamente por URBLOG - Dirigível para Logística Urbana. Este projeto produziu novos conceitos aplicáveis a dirigíveis, os quais foram submetidos a processo de proteção de invenção através de um pedido de registo de patente. A equipa de inventores é constituída pelos seguintes elementos:

- *Rosário Macário, Instituto Superior Técnico;*
- *Vasco Reis, Instituto Superior Técnico;*
- *Jorge Silva, Universidade da Beira Interior;*
- *Pedro Gamboa, Universidade da Beira Interior;*
- *João Neves, Universidade da Beira Interior.*

As partes da presente dissertação relevantes para efeitos do processo de proteção de invenção estão devidamente assinaladas através de chamadas de pé de página. As demais partes são da autoria do candidato, as quais foram discutidas e trabalhadas com os orientadores e o grupo de investigadores e inventores supracitados. Assim, o candidato não poderá posteriormente reclamar individualmente a autoria de qualquer das partes.

***Covilhã e UBI**, 1 de Outubro de 2015*

(*Sara Emília Cruz Claro*)

Dedicator

I want to dedicate this work to my family who always supported me.

To my parents, for all the love, patience and strength that gave me during these five years.

To my brother who never stopped believing in me, and has always been my support and my mentor.

To my sister and my lovely nephews, for all the love and support.

I also want to dedicate this work to my boyfriend, Tiago, who, undoubtedly, without his effort, it would not be possible to finish this stage of my life in five years.

“*Every man is the architect of his own fortune.*”

Sallust

Acknowledgements

I want to give my sincere thanks to all who believed in me and supported me over these five years.

To my family, for all the love, support and patience and to my soulmate Tiago, that was always my support, my best friend, and for helping me overcome all the difficult moments of this journey. I love you all!

To the friends and great colleagues that I made along this journey. Without forgetting my housemates, that made my stay in Covilhã even better and never boring.

To my advisor, Professor Jorge Miguel Reis Silva, whom I am grateful for all the knowledge, patience, and time spent during the preparation of this dissertation. Thank you for the friendship and I'll never forget what we did for me. I also want to thank to my co-adviser Professor Pedro Vieira Gamboa, for the knowledge and all the advises that improve my dissertation.

To João Neves, who was essential to this Project. My gratitude for the effort, time spent, knowledge passed to me and all the advices that will be useful for all my life.

To Tiago Santos, my partner in this journey, for the help and patience. I also want to express my gratitude to Laura Martins and Inês Cruz for the availability whenever needed.

To Professor Rosário Macário and Professor Vasco Reis from Instituto Superior Técnico, for their time and participation in this work.

To *Santos Esteves- Representações Lda*, especially to Sr. Nuno Esteves, for the amiability and for offering essential material to complete this work and to *Citeve* (Centro Tecnológico das Industrias Têxtil e do Vestuário de Portugal), for information that made my ideas clear and help given, especially to Engº Helder Rosendo.

To my 'guardian angels' who always looked for me, and never allowed me to give up.

Resumo

Encontramo-nos numa era em que assistimos ao aumento da procura de transportes alternativos. Este interesse advém do aumento do preço dos combustíveis fósseis, devido à sua escassez, da poluição ambiental além do congestionamento das infraestruturas. Uma alternativa será o uso de dirigíveis híbridos, que poderá vir a colmatar as falhas, acima mencionadas, dos transportes mais usados atualmente. Por isso, o estudo desta tecnologia tem sido cada vez mais aprofundado em todo o mundo. Desta forma, o objetivo desta tese visa, principalmente, o planeamento de construção da estrutura e *gasbags* de um protótipo de um dirigível híbrido com um novo conceito de estabilidade e controlo.

Antes da construção deste protótipo à escala do projeto real, houve a necessidade de fazer testes de conceito em protótipos mais pequenos. Assim, um *blimp* em PVC foi adaptado para estes testes, perfazendo três protótipos. Os dois primeiros (1 e 1.5) tiveram o objetivo de testar a estabilidade e controlo de todas as superfícies e o último (2.5) de testar o desempenho de um dirigível *quad-rotor* com controlo de passo fixo.

Após estes testes estarem concluídos, passou-se à construção de uma secção da estrutura do protótipo final, chamado de Protótipo 3 com cerca de 9 metros. Requisitos iniciais de projeto deliberaram que a elaboração desta componente teria que ser feita à mão, tornando assim obrigatório um estudo da melhor forma de o conceber, otimizando assim o tempo e qualidade de construção da estrutura completa. Da mesma forma, houve a necessidade de estudar-se materiais e o melhor método de construção de *gasbags* para a retenção de hélio.

Palavras-chave

Dirigíveis, manufatura de dirigíveis rígidos, manufatura de estruturas de dirigíveis, manufatura de *gasbags*.

Abstract

Nowadays we witness a growing demand for alternative means of transportation. This interest stems from the rising price of fossil fuels, due to its scarcity, environmental pollution beyond the congestion of infrastructures.

An alternative is the use of hybrid airships, which may fill the gaps mentioned above of the transport commonly used today. Therefore, the study of this technology has been increasingly extensive throughout the world. Thus, the objective of this dissertation aims, essentially, the manufacture planning of a Prototype's structure and gasbags of a hybrid airship with a new concept of stability and control.

Before the construction of this Prototype, there was a need to do concept tests in smaller prototypes. Thus, a PVC blimp was adapted for these tests, and for these adaptation was given the name prototypes too. The first two of them (1 and 1.5) had the objective of testing the stability and control of all surfaces and the last (2.5) to test the performance of a quad-rotor airship with fixed pitch control.

After these tests had been completed, the next step was the construction of a section of the structure of the final prototype, called Prototype 3, with approximately 9 meters. Initial project requirements, decided that the development of this component would have to be done by hand, thus was essential a study of the best way to conceive, in order to save time and increase the build quality of the complete structure. Likewise, it was necessary to study the best gasbags materials and construction, so that they have the best performance in helium retention.

Keywords

Airship, rigid airship manufacturing, airship structure manufacturing, gasbags manufacturing.

Table of contents

List of figures

List of tables

List of acronyms

EVA	Ethylene-vinyl acetate
ATG	Advanced Technologies Group
CNC	Computer Controlled Cutting
LDPE	Low-density polyethylene
LTA	Lighter than air
MET	Metalized
PET	Polyethylene terephthalate
PLA	Polylactic acid
PTFE	Polytetrafluoroethylene
PVC	Polyvinyl chloride
PVDC	Polyvinylidene chloride
PVF	Polyvinyl fluoride
STP	Standard conditions for temperature and pressure

1. Introduction

1.1 Motivation

Airships had their golden age in the 1930s, but have fallen into disuse after the accident of the German model Hindenburg. Currently, the ideal of 'green' transports, which exhibit low fuel or electricity consumption and produce less pollutants, is in vogue. Hence it is so important further research on alternative transport that, moreover also, allow the decongestion of cities due to traffic. Thus returned to be necessary a deepen knowledge in the field of airships in order to make them a new option.

However, this means of transport has some disadvantages, among them, the difficulties of control and stability, making this study the largest area of interest. Allying today's latest technology of control, stability, propulsion, structures and materials to the 'airship' concept, it is possible to fill all the disadvantages of the past making this the future of transport using clean energy, serving mainly for surveillance, advertising, recreational and freight transportation.

As research about this a technology almost stagnated, it is anticipated further development work and adaptation to new technologies, which makes inherent and essential the search of new construction methods due to the use of new materials and configurations.

This dissertation is part of the project ‘UrbLog’, made in partnership between the Universidade da Beira Interior and the Instituto Superior Técnico, referring to a new concept of hybrid airship, more stable and controllable.

To build a scale prototype of this project, is necessary to test all parts of the conceptual design to validate concepts, and find solutions to problems that may arise in terms of construction method. As in any other new technology project, all initial ideas must be validated before, to be possible an appropriate constructive planning, for the development of the final design could be optimized in terms of time, money and quality.

1.2 Object and objectives

The object of the current dissertation is the study of manufacturing techniques to apply on the construction of a prototype that will test a new concept of hybrid airship, and the adaptation of a blimp for small conceptual tests.

The first objective is to adapt a blimp for tests on stability and control. If these tests are inconclusive, it is demonstrated that it is not feasible to continue the project. Hence, this practical work of adaptation is essential to the project.

The second and most important objective is the development of a manufacturing plan of the final Prototype 3's structure and gasbags. Within this, we can divide into several sub-objectives. The first is getting the best manufacturing method for making the structure of the prototype 3. The second is to investigate materials to make helium gasbags and determine the best manufacturing techniques. The third is to design an assembling jig for Prototype 3 final assembly.

1.3 Dissertation structure

This dissertation is divided into five chapters.

The first chapter is the study introduction, which is divided into three sub-chapters, the motivation, the object and objective, and the structure of the dissertation, respectively.

The second chapter corresponds to the state of art and contains the general study of the construction of airships up to today. Includes general definition of airships, the current manufacturers, methods used to construct the structure and gasbags, materials used for the construction of gasbags and a brief study about the helium permeability and its gas permeation theory.

In the third chapter is possible to observe the description of all blimp adaptation work for stability and control tests.

The fourth chapter refers to the case study, where was studied the best manufacture methods for the structure and gasbags of Prototype 3. It also includes a brief study of materials, its permeability and the conceptual design of an assembly jig for the final assembly of Prototype 3.

The fifth (and last) chapter contemplates the dissertation synthesis, the final considerations and the prospects for future work in this matter.

2. State of art

2.1 Introduction

This chapter aims to give a general view of the state of the art of airships manufacture. Will start with a brief introduction to airships, then deepening the construction methods applied to them. As this work mainly aims at the construction of the structure and gasbags, these are the two most studied aspects.

The construction of these two important components of the airship requires a general planning. That is, for the construction of the final prototype, one structured planning is needed and inside that, the design of special tools. Thus, this chapter also contains the study of airship and other aircraft jigs.

2.2 Airships manufacturing

2.2.1 Airships – definition and classification

An airship, also known as dirigible, is a type of aerostat, or lighter-than-air (LTA) aircraft. Basically is a powered balloon with a means of propulsion and its shape is modified in order to be an effective vehicle. This way, its format must be studied in order to reduce aerodynamic drag and enhance the controllability.[1] So the common airship formats have some similarities to conventional aircraft.

There are four categories of airships (Fig. 1): Rigid, Semi-Rigid, Non-Rigid and Hot Air Airships. The rigid airships have an internal frame. This structure holds up the shape of the airship. A Semi-Rigid airship usually contains a rigid lower keel construction and a pressurized envelope above that. The rigid keel can be attached directly to the envelope or hung underneath it. As for Non-Rigids, this kind of airships is also known as Blimp and basically a large balloon full of gas. Its shape is maintained by the internal overpressure. The last type are the Hot Air Aiships, or Thermal Airships, although they are in another category, are part of Non-Rigid because is the same concept. The difference is the gas, in this case, this type of airship use hot air [1, 2].

Currently, have been a greater investment in the construction of vehicles that derive most of their lift from Aerostatic principles, on the other hand their useful cargo capacity rely on Aerodynamic lift. These new concepts is known generically as Hybrid Airships [3].

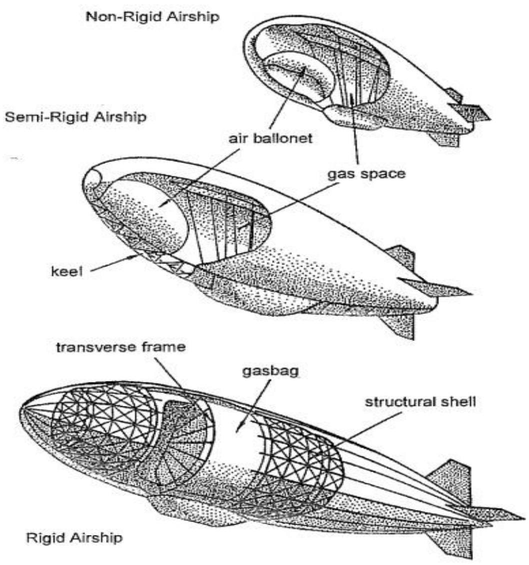


Fig. 1 - Airship types [1]

2.2.2 Rigid airship manufacturing

Considering that this project aims to build a rigid airship, only this type of construction will be studied.

Usually, rigid airship contained a rigid hull frame, generally built up of longitudinal girders which are connected at intervals by polygonal ties, constructed of a lightweight but strong material providing a rigid structure within which were the lifting gas cells; machinery; fuel and living/working space. A separate cover went over the outside of the framework to provide streamlining and weatherproofing [4].

Zeppelin is an example where this type of construction is applied. This is a type of rigid airship whose name was a tribute to Ferdinand von Zeppelin, a German Count, who pioneered the development of rigid airships in the twentieth century.

On Zeppelin airships, was usual that every second tie was braced athwart ships by a radial wire truss, through the hub of which a steel hawser runs from stem to stern. Both the hawser and the radial truss wires were fitted with turnbuckles whereby the whole framework may be tightened up when required. The radial, or tie, trusses form the compartments in which from individual gas-cells are housed; the cells were drum-shaped and were fitted with an inflation appendix and a relief-valve [5].

An example is the Hindenburg Zeppelin (Fig. 2, a large German commercial passenger-carrying. This ship was built with triangular duralumin girders forming 15 main rings, connecting 36 longitudinal girders, with a triangular keel at the bottom of the hull, an axial corridor at the center of the ship, and a cruciform tail for strength [6].

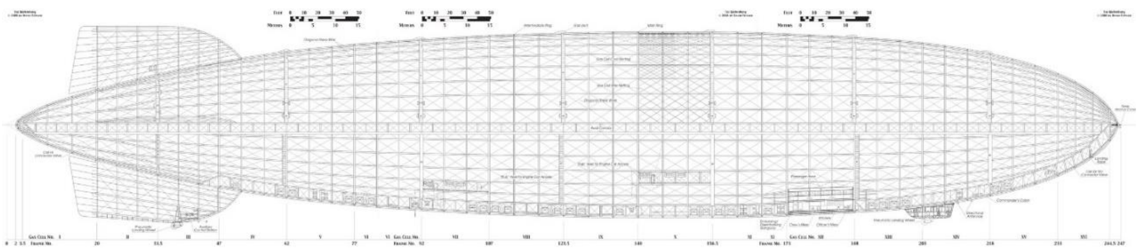


Fig. 2 - Hindenburg profile, showing major elements and numbering system for gas cells and frames [6]

The construction of this kind of airships is time-consuming, strict and expensive. Considering as the initial construction requirement the size, this undergoes the need for a large space, a hangar.

The hangars that were constructed for this purpose are huge infrastructures, the biggest ever created to construct airships [7]. Due to the complexity of manufacture, the hangar should be provided with Industrial tools of construction (jigs) and good working conditions. The construction of this airship forced the use of welding techniques for light alloys for the fabrication of lattice-girders. After this, all parts are attached on a support structure, as shown in Fig. 3. This support structure allows that all components are placed in the correct place, while the construction is not complete. After the building, this framework of wood or metal is removed. This is the basis of building for all rigid airships.

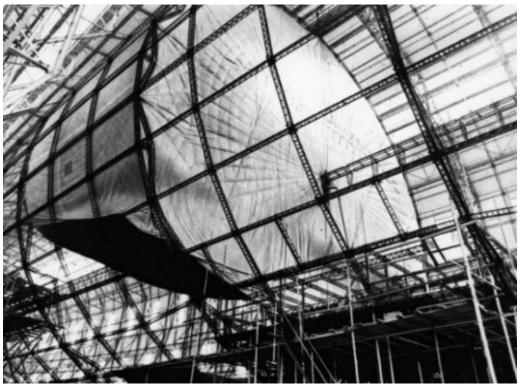


Fig. 3 - Hindenburg under construction [6]

After the disaster of LZ 129 Hindenburg, that caught fire and was destroyed, the manufacturing of these 'air monsters' fell into disuse, decreasing the evolution of this kind of construction until a few years ago, when it started to believe in this technology and to focus on their research.

However, nowadays there are only a few companies manufacturing rigid airships, and so there are few production hangars.

2.2.3 Rigid and Semi-Rigid airships manufacturers nowadays

As mentioned above, airships are divided into 4 categories: rigid, semi-rigid, non-rigid and hot air airship. Concerning the manufacture, the requirements to build semi-rigid and rigid structures are very similar, because both have an internal structure.

After the disaster with Hindenburg, was not so common the manufacture of airships, but there are still some companies that invest in this mean of transportation. Due to the complexity of building, and requirement of large hangars, only a few remaining countries have these conditions. Nowadays there are very few construction hangars for rigid and semi-rigid airships, and the best known are in Germany, England and the United States of America.

In Germany, there is the *Zeppelin Luftschiftechnik GmbH* descendant of the ancient industry of Count von Zeppelin, was established in September 1993 to design, build and operate a semi-rigid airship with the new technologies available, leading to the "NT Programme".

There is also the CargoLifter AG, founded in September 1996 in order to develop the project of a multifunctional semi-rigid airship, the CargoLifter CL-160, to carry heavy loads and surplus volumes. For this purpose was built in the area of a former Soviet base, a huge hangar, with 360m long, 210 m wide and 107 m high.

Further north, England holds the 'Advanced Technologies Group (ATG)' established in 1996 to continue with the activities of the former Airship Industries Company, responsible for British airships designated Skyship 500/600 series. It has two projects at this moment, the SkyCat (Fig. 4), which is a hybrid airship, and StratSat, a stratospheric airship unmanned to serve as telecommunications platform.

Fig. 4 - Skycat Prototype [8]

In the United States there is the World Aeros Corporation, which was established in Ukraine in 1988 and transferred its activities to California in 1993. It produces a variety of vehicles "lighter than air", manned and unmanned for military and civilian applications. In 1999 it was created the Aeros Airship Company in order to develop large airships: the Aeros D-1, with a capacity of 14 tons, and the Aeros D-4, to 124 tons of cargo [9].

In Portugal has never been common the development, construction and operation of airships, but a few years ago Nortávia, an aerial transportation company, started the project of a solar airship, Gaya. Until now the final design has not yet been conceived, the prototype was the only one manufactured in Portugal [10].

2.3 Jigs design in aeronautical industries

Any aircraft project have a complex structure, and for each one is essential its manufacturing planning. If this planning is done well, optimizes its production mainly in terms of time, quality and price.

A rigid airship is conceived as a complete structure, but for manufacturing purposes must be divided into sections, or main components that are split into sub-assemblies of decreasing size, resolved into individual detail parts. In any industry a significant factor, in conjunction with the quality of the product is its productivity. This isn't an exception in aeronautical industry and because of that a good manufacture plan is required. Inside this plan is necessary a good design of floor assembly jigs, to build every single part [11, 12].

In summary, a JIG is a fixture used to locate, clamp and support all the elements of a piece, putting them together on the correct place, in a rigid unit during a manufacturing operation. That it is known as a template that ensures that each part is accurately made to the shape of the template and that considerably depends of the skill of the operator [12, 13]. So, this involves a generator tool frame, locator and clamp placement to guarantee that the assembly components is made properly respecting the required tolerances. For each different project is necessary a tool designer that analyze the best tool design to warrant that the assembly process is performed correctly without causing accessibility or ergonomic problems and need to considerate the accuracy and rigidity too, followed by ease of use, and economy in construction. If this tool is well designed will ensure the interchangeability and accuracy of parts manufactured, minimize the possibility of human error, permit the use of medium-skilled labor, reduce the manufacturing time and allow the production of repeat orders without retooling [11, 12].

(a) (b)

Fig. 5 - (a) *Cessna Citation X* fuselage assembly jig [14]; (b) Airbus A300-600ST transport jig [15]

There are a lot of examples of jigs used in aircraft manufacturing, some of them are presented in the previous figures, were is shown a *Cessna Citation X* fuselage assembly jig (Fig. 5a) and an Airbus A300-600ST transport jig (Fig. 5b).

Also for the construction of model aircraft are developed jigs, for example, for the construction of wings ribs is usually design a jig table that contains the template of the piece (Fig. 6).

Fig. 6 - Construction Jig for wings ribs [16]

In conclusion, one jig is a manufacture supporting tool, designed according to the requirements of the type of construction, the shape and purpose as transportation, assembly, manufacture, placement and other needs.

2.4 Rigid airship structure manufacturing

As mentioned above, a rigid airship shape can be maintained independent of envelope pressure because the envelope is usually supported by a lightweight but strong framework. Usually, the framework of the external support structures, are composed of transverse girders forming approximately circular frames, and longitudinal girders successively through the length, as shown in Fig. 7. Transverse girders, are connected by longitudinal girders, and are cross-braced with pre-tensioned metal wires to confer adequate rigidity upon the whole assembly for increased structural strength. This structure was normally made by aluminum alloys and all the girders made of trusses [4, 17].

All parts of the beams are pre-assembled. The Fig. 7 shows the assembly of a circular frame where the 'rings are built flat on the floor and hoisted into place, the wheel-like markings on the floor are jigs for smaller circular frames' [18].

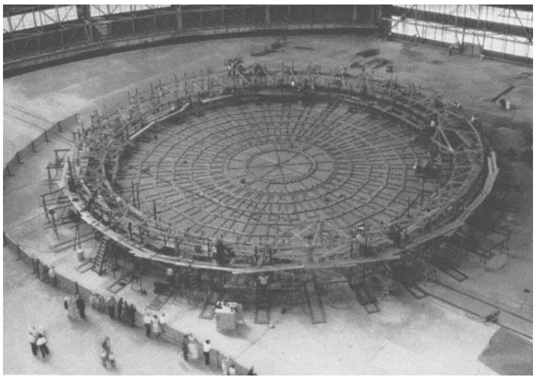
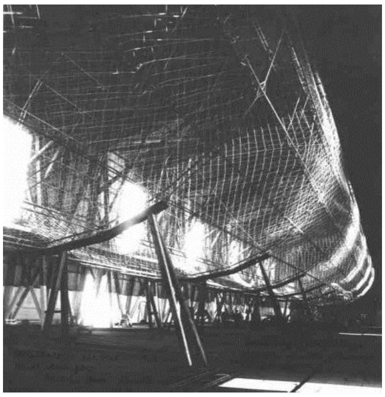
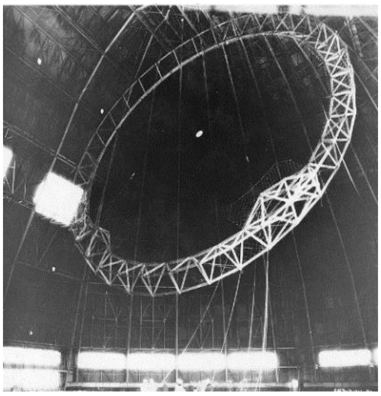


Fig. 7 - Circular frame assembly Jig of a rigid airship structure [18]

After the beams, circular and longitudinal frames be ready, they were assembled. In the case of Zeppelin LZ 1 (Fig. 8a) the structure was mounted over an aluminum frame supported by wooden structure [19]. In the USS Akron (ZRS-4) the rings of circular frames were erected using strong cables (Fig. 8b).



(a)



(b)

Fig. 8 - (a) LZ-1 internal frame jig; (b) Erecting the first ring of USS Akron's frame, March 1930 [18]

Through time, new assembly methods have been developed. As an example, Durr Ludwig patented an Auxiliary device for assembling airships (Fig. 9). This invention is a jig made of wood, light metal or high grade steel shapes that can readily and rapidly assemble the airship body [20].

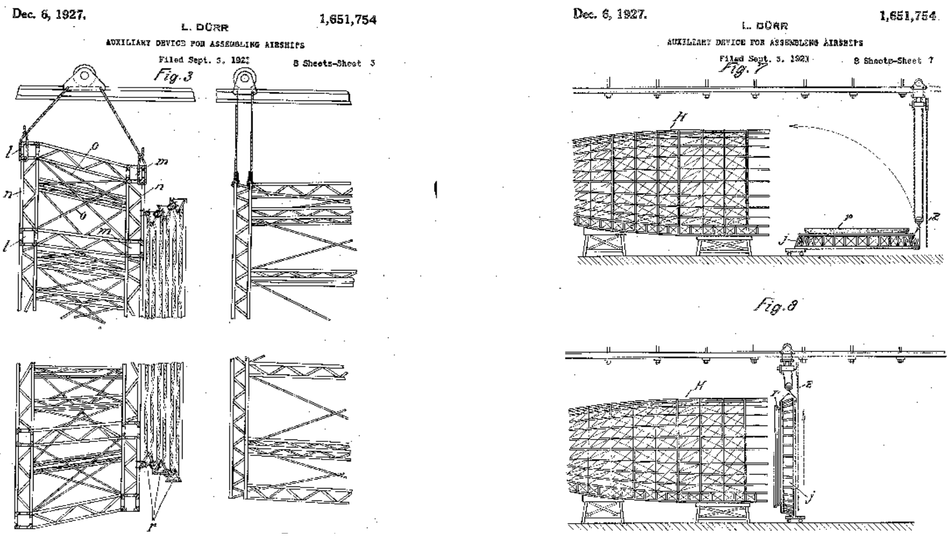


Fig. 9 - Auxiliary device for assembling airships [20]

2.4.1 Truss structure manufacturing

The structure of rigid airships should be as light as possible and extremely strong. Initially they were metallic, for example using lightweight aluminum alloys, but new materials have been developed over time and the beams of metallic trusses could be replaced by, for example, composites. At this moment 'lightweight carbon fiber rods and truss structures with high stiffness, high strength and sufficient durability are more and more important for advanced transportation technologies' [21]. If metal alloys are used, the trussed beams can be made directly with the desired shape by metal casting and molding. The join of different parts is made by welding or bolting. When the trusses are made by composite material, in particular carbon, the part can also be made directly with the desired shape. In this case the part is laminated and consists of a polymeric matrix and a reinforcing material, carbon. The joints between beams can be made by application of this polymer matrix, or even screwed.

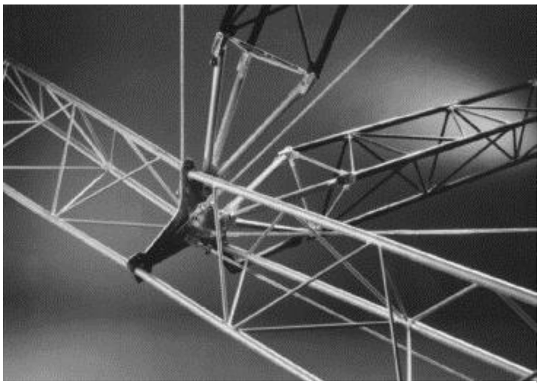


Fig. 10 - Beam-like truss structures of the new Zeppelin NT [21]

The new Zeppelin NT has an internal structure which combines aluminum and carbon fiber. The Fig. 10 shows a truss beam from structure of the Zeppelin NT that comprise aluminum and carbon fiber trusses [21].

2.5 Gasbags manufacturing

The *UrbLog Project* refers to a hybrid airship, and its shape is given by a rigid structure. Therefore, unlike non-rigid airship, the helium internal pressure, an inert gas chosen for sustain, don't ensure the shape of the aerostat. It is normal that, this type of airships have internal compartments for retaining the gas. These compartments are called gasbag and are usually made of fabric ideally not permeable.

Fig. 11 - Britain's R 101 airship under construction at the Royal Airship Works, Cardington

Although, the purpose of the gasbag is not the same as the envelopes of non-rigid airships, the behavior of both should be very similar, and therefore, have similar fabrication requirements. In the case of gasbags, as they are not in contact with external conditions, it does not require as high resistance to environmental degradation, but is an important point to consider for the part lifetime.

Thus, the required properties of the material for manufacturing Gasbags are [1, 23]:

- High strength to weight ratio to minimize the weight of the gasbag;
- Resistance to environmental degradation trough temperature and humidity;
- Good tear and abrasion resistance to give damage tolerance;
- Low permeability to minimize helium loss. This loss results in loss of operational capability and increased operational costs;
- Joining techniques that produce strong and reliable joints, not subject to creep rupture;
- Minimum price;
- Maximum material life vs. ease of field repair.

2.5.1 Materials

In the golden days of airships, the development in the field of Textile Engineering was poor, but over the years there has been great progress in the research of new materials. With the development of synthetic materials, the textiles used in airship manufacture had undergone many changes.

In the beginning of rigid airship, it is known that gas cells of earlier German Zeppelins were made of goldbeater's skin (the outer membrane of cattle intestines). Latter, Hindenburg innovates using a new material the construction of the gas cells. This material 'was made by brushing layers of gelatine onto a sheet of cotton, this gelatine film was sandwiched between two layers of cotton to create the fabric for the cells' [6].

About more materials used in the construction of gasbags, there is almost none bibliography, so the investigation of the state of the art was continued based on the development of textiles for the envelopes.

For the first envelopes were used natural fibers, including cotton and rubber. This envelopes were made by plied rubber coated fabric, two or three plies of cotton fabric bonded together with natural rubber. The cotton plies were based relative to each other in order, to claim shear strength, stiffness and tear resistance. The natural rubber sealed the fabric. Firstly, material was joined by a mix of sewn and bonded joints to maintain good contact in the joint while the bonding, agent rubber cement, cured. To reduce permeability, the envelope was sealed with paraffin on the inner surface. However, this material had poor properties by the modern standards [1].

With the technological evolution, new materials were found, and the first use of synthetic products in envelope materials was the replacement of natural rubber by neoprene (chloroprene) rubbers. This one has much improved weatherability and a lower permeability than natural rubber. This properties allowed less maintenance of the envelopes, because the life of material was extended. But, unfortunately, the material still had a very limited strength. Latter, new base fabrics made from synthetics fibers was found, with better strength for low weight, such as Polyamides (nylon), and Polyesters [1].

Nowadays, new envelope materials have been developed, which is the case of laminated materials. This modern materials allows that in the same film there are several fabric layers with different properties. Together they have the required properties for the envelope [1].

Generally, envelope laminate film is made of gas retention, woven load bearing and environmental/ weathering protection layers that are bonded together with an adhesive layer, like is shown in the Fig. 12.

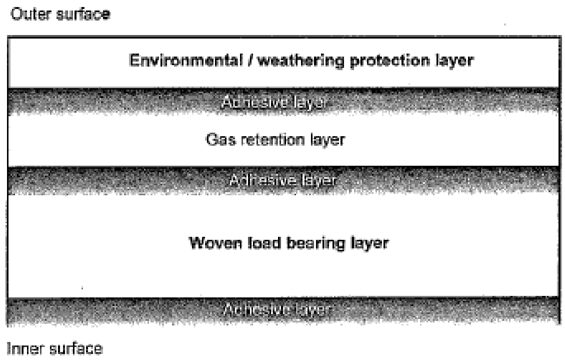


Fig. 12 - Section trough typical laminate material [1]

For woven load bearing layer, is required that the material need to be flexible, so this component needs to be a woven fabric. So, there is a large selection of synthetics fibers with relevant properties. The Table 1 makes a comparison of the most common synthetic fibers used.

Table 1 - Comparison of the most common synthetic fibers used in Envelopes [1]

Material	Fibre Specific Gravity	Fibre Tensile Strenght GPa (lb/in^2)	Fibre Modulus GPa (lb/in^2)
Polyester	Low	Excellent	Yes
Polyamide	Low	Poor	Yes (with adhesives)
Aramid-high modulus	Low	Fair	No
Aramid - Low modulus	Very Low	Fair	Yes

In the case of gasbags that will be used in the prototype 3, studied in this work, the most important properties are its permeability and adhesion to other materials. The material should have a low permeability, in order to lose less gas as possible, and, as the construction of this part will be done manually, it should be used a material which is easily sealable. Thus, the choice of material to use in gas retention film is very important.

In Table 2 are listed some materials commonly used in the manufacture of envelopes, that could also be applied to our gasbags.

Table 2 - Typical Properties of film materials for possible use in laminated materials for a gasbag. (Main properties) [1]

Material	Gas Permeability	Adhesion to Fabrics/Film	Heat Sealable
Polyurethane	Low	Excellent	Yes
Polyvinyl Fluoryde	Low	Poor	Yes (with adhesives)
Polyester	Low	Fair	No
Nylon	Very Low	Fair	Yes
PVDC Copolymer (Saran)	Very Low	Fair	Yes
PTFE	Fair	Poor	Yes (some grades only)
Low Density Polyethylene	Fair	Poor	Yes
PVC	Fair Low	Excellent	Yes

Table 3 - Typical Properties of film materials for possible use in laminated materials for a gasbag. (Secondary properties) [1]

Material	Tensile Strenth	Flex Fatigue Resistance	Weatherability
Polyurethane	4,000-10,000	Good	Good
Polyvinyl Fluoryde	8,000-16,000	Excellent	Excellent
Polyester	25,000-45,000	Fair	Fair
Nylon	10,000-17,000	Excellent	Poor
PVDC Copolymer (Saran)	7.000-16.000	Fair	Poor
PTFE	3,000	Good	Excellent
Low Density Polyethylene	1,000-2,300	Excellent	Good (if pigmented)
PVC	1,000-3,000	Good	Good

The properties were divided into two tables. The first (Table 2) shows the main properties required for the gas retention film to use in this project, and the second (Table 3) shows important priorities, but not so relevant for the design of this prototype.

Normally, the preferred material is polyester, being the polyester film (Mylar –Du Pont) the most common component. This film has low permeability and is relatively strong and stiff. Usually the gas retention film already consider the weathering component, but when not, is usual the use of a protective film in the weathering protection layer. A comparison of fabrics used previously is shown in Table 4.

Table 4 - Properties comparison of fabrics [1]

	Neoprene	Polyurethane	Polyvinylfluoride
Properties	SG 50% greater than polyurethane or PVF	Very low helium permeability	Very low helium permeability
	Modest weatherability gives 3 years life with frequent maintenance i.e. painting.	Very good handling properties and crease resistance	Resists fungal growth
	Must be joined with adhesive	Good weatherability gives 5 year life with modest maintenance	Excellent weatherability gives 15 to 20 year life with no maintenance
		Very easy to handle and join (by adhesive or heat bonding)	

Polyvinylfluoride (PVF) film, has proven to be greater resistant than most synthetic materials, and his long life with almost zero maintenance made that one the most common material used for weathering protection of envelopes [1].

2.5.2 Helium permeability – Gas permeation theory

It was previously established that the lifting gas chosen for the 'UrbLog' prototype would be helium. This gas have very small molecules that are notoriously difficult to contain, to avoid leakage [24]. Because of that, the gasbag material needs to have a low helium permeability, because the loss of helium translates into lifting force deficit during the airship operation, and also increase the cost of operation too. So it is very important to know the permeability of the material that will be used.

By the gas permeation theory is possible to obtain the volume of gas passing through an area per unit time across a sample [25].

The transport of gases through a solid membrane is a solution-diffusion mechanism where the permeants dissolve in the membrane down a concentration gradient. This consists of three processes [25, 26]:

- Absorption of the permeant into the polymer;
- Diffusion through the polymer;
- Desorption or evaporation of the permeating species from the polymer surface and removal.

The driving force behind the transport process which involves the sorption, diffusion and permeation is the gradient concentration between the two sides of the membrane. This process is designated by Fick's laws of diffusion described by [26]:

$$J = -D\left(\frac{\partial C}{\partial x}\right), \ \frac{\partial C}{\partial t} = D\left(\frac{\partial^2 C}{\partial x^2}\right) \tag{1}$$

Where,

-J is the flux in the direction of the flow $\left[{}^{mol}/_{m^2.s}\right]$,

-C is the concentration of permeant $\left[{}^{mol}/_{m^3}\right]$,

-t is the time [s],

-D is the diffusion coefficient $\left[{}^{m^2}/_{s}\right]$,

-x is the position within the membrane down the concentration gradient [m].

After some permeation time, the steady-state is reached and that implies that the concentration is remaining constant at all points within the membrane. Under these conditions and by introducing boundary conditions for a planar sheet, it is possible to describe the flux by:

$$J = -D\frac{C_0 - C_1}{l} \tag{2}$$

Where,

-C_0 and C_1 are the permeant concentration upstream and downstream side of the membrane;

-l is the membrane thickness [cm].

In a system where a gas diffuses through a membrane, the concentration may be replaced by the gas partial pressure. So J is described by:

$$J = -P\frac{p_0 - p_1}{l} \tag{3}$$

Where,

-P is the permeability coefficient $\left[{}^{mol}/_{m.s.Pa}\right]$,

-p_0 and p_1 are the gas partial pressure on either side of the membrane [Pa].

If the diffusion coefficient is constant over the pressure range, the permeability coefficient may be rearranged to:

$$P = DS \tag{4}$$

Where,

-S is the Solubility coefficient$\left[{}^{\mathrm{m}^3\ (\mathrm{STP})}/_{m^3.\,\mathrm{Pa}}\right]$.

To calculate the permeability coefficient is necessary to measure the flux and pressure gradients in the both side of the film, in order to determinate the diffusion coefficient [26].

2.5.3 Envelope manufacturing methods

The processes used in airship envelope fabrication must be properly defined to guarantee a high quality airship envelope. The endurance of the airship envelope depends not only of the material used but also on the design, its seams and accessories too, as well as the procedures for fabrication and final assembly [23].

For airship with large infrastructure, there is no literature available about the construction methods of envelopes or gasbags. However, for small hand-made blimps, it was possible to determine some methods. In all of them, the production starts by defining the pattern and, consequently, the number of sections in which the piece will be split to achieve the desired shape after their union, as we can see in the following figure Fig. 13 [23].

Fig. 13 - Handmade blimp [23]

As for the sections joints, it is needed to take into account the type of material that was used for manufacturing the envelope/gasbag.

For small homemade blimps it is preferred that the material is heat sealable, as this is the most common form of union. However, sometimes it is not possible to apply this method to some of the used materials, such as envelopes made of polyester film. In this case the joints must be made using contact adhesives. Silicon sealant and cyanoacrylate can work, but silicone is heavy and takes a long time to cure, while cyanoacrylate is not flexible, so the joint cracks easily. One choice for the contact adhesive is *UHU Power Stick*. In the case of use of this glue to make the joints, it must follow the following procedures [27]:

1. Clean both joint surfaces;
2. Spread *UHU Power Stick* across the joint area of each surface;
3. Wait a minute for it to dry;
4. Press the two sections together and make the joint;

5. Apply some heat in the joints, with the help of an iron to unify the glue along all contact section.

The joins must be made as pictured in Fig. 14 (a) and (b).

Fig. 14 - (a) Single lap joint; (b)Single strap joint [28]

If welding can be used in this materials, start by setting the welding area in each section. After this being delineated, join the two sections and apply heat with an iron so that the edge is welded. This procedure must be followed for all the sections until achieve the desired shape. For the envelope shown in Fig. 13, it was welded by radio frequency heat welding as can be seen in Fig. 15.

Fig. 15 - Radio Frequency heat welding [29]

2.6 Conclusion

The construction quality of an airship is crucial to its good performance. The type of construction, methods and tools vary by size, type of structure, materials and kind of operation. So it is important a good constructive planning and design tools for optimize the production in terms of time, cost and errors.

As such, and because there is no rule in terms of construction, this state of the art contemplated comprehensively a summary of the manufacture of rigid airships, building structures, gasbags and design tools.

Since the manufacture of rigid airships is not as common as up to 1920, the available literature on the construction methods of the components is very short, such as information on the manufacture of gasbags and their materials. With this it is necessary determine, in a practical way, the best methods to apply in the manufacture of the Prototype 3 of 'Urblog' Project.

3. Adaptation of a blimp for stability and control tests

3.1 Introduction

This dissertation is part of the project 'UrbLog'. This project aims the development and construction of a hybrid airship with an innovative stability control system, and is part of a partnership between Universidade da Beira Interior and Instituto Superior Técnico.

Airships are known for the difficulty to control and stabilize them so, in this project, this will be the main area of study. Due to the inexperience of the working group on airships, there was the need to make flight tests to better understand the concepts of control and stability and for that was used a small PVC blimp. It was important to confirm this project feasibility, validating, this way, the construction of prototype in real scale, the Prototype 3.

Since the monetary and logistic conditions for the construction of Prototype 3 were not yet available, it was necessary to optimize the time and continue the research into smaller prototypes that were cheaper and required less resources. They also allowed the optimization of the research because each of these prototypes has been adapted to the specific area that we want to investigate. The PVC blimp was then adjusted for a set of tests, and in each one was made a different adaptation. So, we call to each of this adaptations Prototype 1, Prototype 1.5 and Prototype 2.5. Thus, this chapter describes all the upgrading works that the blimp suffered.

Spite of not being the main objective of this work, it was an important part that defined the ongoing experimental work for the planning of the construction of Prototype 3. Therefore, and for a better understanding of the work developed, the blimp's adaptation is described only in this chapter.

It is important to refer that the stability and control tests were part of another dissertation, and therefore placement of parts, materials and purposes of the tests are justified in that document [30]. Thus, this chapter only describes the construction work carried out in accordance with the requirements.

3.2 Prototype 1 – adaptation for stability and control tests

Prototype 1 consisted of the adaptation for stability and control tests of a previously manufactured PVC Blimp. It was therefore necessary to find support solutions for wings and propeller, finding the best manufacturing method for wings and fittings.

First of all, the balloon was filled with air, and then was bonded a measuring tape around (Fig. 16). This tape, glued lengthwise, aimed to help to do symmetrical marking to attach all the pieces.

Fig. 16 - PVB Blimp measurements

3.2.1 Carbon fiber lamination

Throughout the project, there was the need to use several pieces of carbon fiber. Therefore, this small sub-chapter explains in a brief way the lamination process used.

It was necessary to use a mould, in all parts made of carbon fiber. The procedure carried out for laminating were as follows [31]:

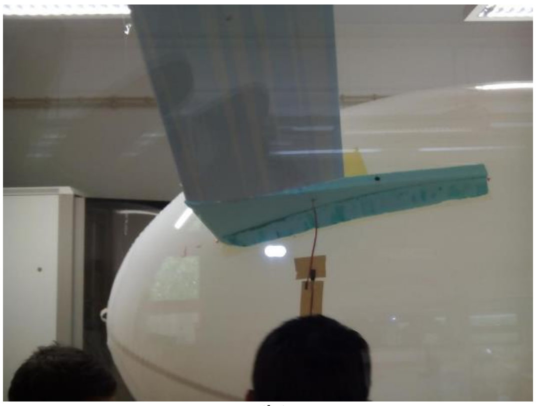
1. Apply Release Agent or brown tape to the mould to prevent the carbon fibre part from sticking to it.
2. Cut the Carbon Fiber. The piece of fabric should be cut according to the size of the mould, and must be divided the best way possible to cover it up. Cutting must be made with a suitable scissor.
3. Weigh the carbon fiber that will be used.
4. Mix Epoxy Resin and Hardener. The amount of the mixture must have the same weight of carbon fiber and the proportion of the resin is 2 parts of epoxy resin with 1 part of epoxy hardener.
5. Apply a bit of resin mixture in the mould uniformly.
6. Lay Carbon Fabric into the mould in order to cover it completely. Check that there is no wrinkles.
7. Apply resin mixture and spread uniformly using a flexible and smooth spatula to don't affect the fabric.
8. Repeat the process as many times as necessary according to the number of carbon fiber layers.
9. Absorb, carefully, the excess of resin mixture with smooth paper.
10. Leave to cure for 24 hours.

11. Remove the piece carefully of the mould and cut the excess.

3.2.2 Wings Manufacture

For carrying out the test it was necessary to build six wings. Four horizontal and two vertical. The material chosen for its construction was extruded polystyrene because it is relatively lightweight, easy to give the desired shape and cheap. The best way to cut accurately throw the extruded polystyrene is hot wire, thereby, after the wings are drawn, they were cut in a hot wire CNC machine. After cut and inspected the wings for defects, they were carefully covered with white duct tape, reaching the appearance shown in the following Fig. 17a and Fig. 17b.

(a)



(b)

Fig. 17 - Extruded polystyrene wings. (a) Wings after manufacture; (b) Assembled wing.

After coating, was made an opening, in the four horizontal wings, to introduce a metal pipe. This circular pipe, had function of a hinger support, supporting the wings but allowing rotational movement, for changing the angle of attack (Fig. 17b).

As can be seen in Fig. 17a, were made some small parts of carbon fiber to allow the connection of the wing to the servo through a metal rod.

These pieces were cut from a laminated carbon fiber board having two layers of fabric.

For the purpose of positioning the horizontal wings in the correct place supporting components have been made. These components made of extruded polystyrene were cut and sanded by hand, until reaches the blimp’s shape.

3.2.2 Support jig manufacturing

Fit components in a balloon filled with air is quite complex. Applying a small force, changes its shape, as well as not remaining stable. All work needed to be carried out by at least two persons for the blimp not to move. So there was the need to build a support jig where the blimp could be supported, but so it does not interfere with the adjustments work.

The solution was to make a support Jig (Fig. 18), that could be modular so it can be transported. Not being an essential part, it was decided that the material to use was extruded polystyrene because it was cheap and easy to cut.

Were then cutted two boards of extruded polystyrene with the profile of the bottom of blimp. These should be hot wire cutted on the CNC machine but its size do not allow cutting of such large parts. Then it had to be handmade, using a sharp blade knife. The assembly and disassembly is quick and easy, as well as fulfilling the intended purpose.

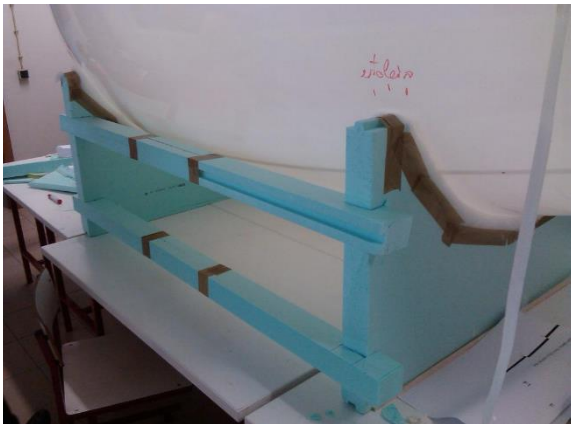


Fig. 18 - Blimp’s support Jig

3.2.3 Manufacture of the landing gear

The Blimp’s material, PVC, was fragile, and because of that, it was needed to safeguard it in landings. For this it was conceived a landing gear.

Once more, this component should be easy to install, functional and lightweight. So, the lower shape of the filled balloon was draw on extruded polystyrene, and then, that was cut with a sharp blade. It was made two supports, with the format shown in the Fig. 19. Then, in each of these, were glued two plastic wheels.

Fig. 19 - Extruded polystyrene landing gear

This landing gear was glued to the blimp with double-sided self-adhesive (*tesa® Flooring Tape Extra Strong Hold)*. Finally, two carbon wires were bonded between the extruded polystyrene parts, which served as tensors, to maintain the landing gear with the desired shape and position.

3.2.4 Tail cone manufacture

The position of the propeller motor was chosen in the conceptual design and it was concluded that this would be on the back of the blimp. However, the filling and exhaust gas valve was at the tail, so, it was necessary to build a motor support structure that could be removable. Necessarily this structure had to be as light as possible.

The solution went through the elaboration of a cone in carbon fiber that fit perfectly in the blimp's tail without affecting the envelope made of PVC. For this purpose, was made a mould of extruded polystyrene, through gluing overlapped layers of this material. This overlap was then cut and sanded manually until it reaches the desired shape. After finishing the mould, it went through a process of lamination with carbon fiber.

The mould was covered with tape so that there were no fiber adherence to this after it has dried. Then carbon wire were placed vertically, dividing the piece into eight reinforcing it structurally. It was also applied a carbon fiber tape with approximately 3 cm wide in the bottom of the mould. Then, the entire mold was covered with fiber, on top of the cone was placed a circumference of pre-made rigid carbon and the entire mold was again covered with carbon fiber. The lamination process of this part was made according to the procedure of subsection 3.2.1.

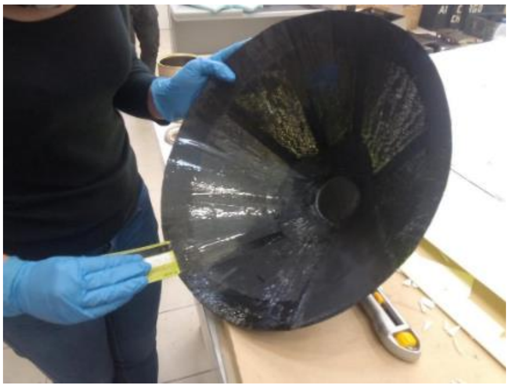


Fig. 20 - Electric motor's support cone manufacture

In order to avoid direct contact between the carbon tail cone and PVC blimp, the contact areas were reinforced with EVA foam. This foam was bonded by contact adhesive. Finally, were made some openings on the top of this part to be possible the motor's housing.

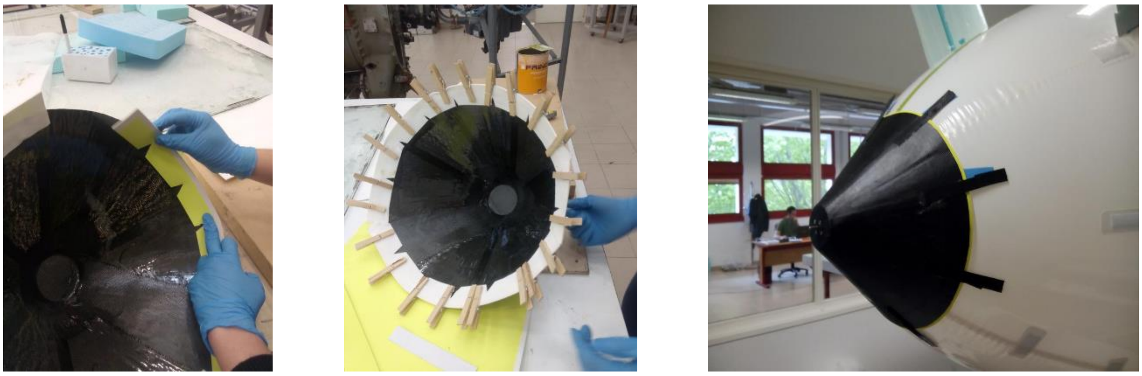


Fig. 21 - Electric motor's support cone addaptation

To secure the cone to tail the Blimp carbon strips were glued around. These strips are cut from a laminated plate previously. The manufacturing process of this card is described in Chapter 3.2.1.

It was glued adhesive Velcro tape at the tips of carbon strips, as at the bonding areas on the blimp's tail. The bonding via Velcro allowed to put and to withdraw the cone easily whenever necessary.

[1]3.3 Prototype 1.5 and 2.5 adaptation for stability and control tests

Since the wings of Prototype 1 were heavier than desired, other set of lighter wings were made for new flight tests. Due to the weight savings, the landing gear was also removed.

3.3.1 Prototype 1.5 - wings manufacture

In order to reduce wings weight, it was decided to build the wings in balsa wood and covering film, as it is commonly used in aeromodelling.

Initially, was printed the template of the wings format and cutted, in a laser machine, the balsa ribs with 2 mm of thickness. The cutting of the ribs must take into account the reinforcement part of the lead, and trailing edge of the wing and spars. These parts were also cut beforehand. For spars and leading edge, has been used a square balsa profile with 10mm thickness, and in trailing edge the reinforcing part has a balsa board of 2 mm thick and 15 mm

---

[1] *Parte da dissertação relevante para efeitos do processo de proteção de invenção referido no Aviso no início deste documento.*

wide. The glue used was *Permabond® ET515 Semi Flexible 15min Epoxy Adhesive 50ml Twin Tube*.

Then it was been carried out the following manufacturing process:

1 – Glue the template under an extruded polystyrene board.

Fig. 22 - Wing manufacture (1).

2 – Place the spar and fit the ribs in the right places according to the template. Glue the pieces with cyanoacrylate.

Fig. 23 - Wing manufacture (2).

3 – Turn the wing around and glue the other spar and the reinforcement part of the leading edge and trailing edge.

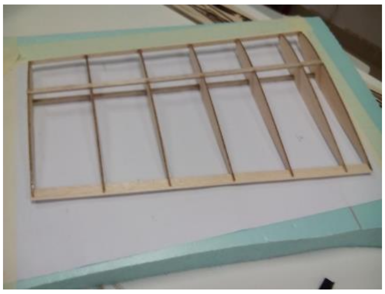


Fig. 24 - Wing manufacture (3).

4 – Cover the leading edge with 1 mm balsa board.

Fig. 25 - Wing manufacture (4).

5 – Glue 2mm thick balsa boards in order to cover the two spars increasing the structural strength of the wing.

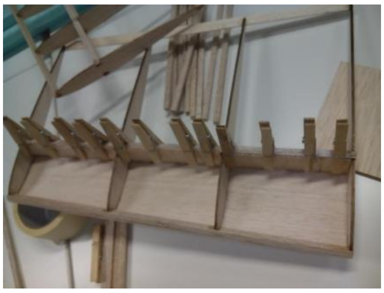


Fig. 26 - Wing manufacture (5).

6 – Glue, on the tops of all the ribs towards the leading edge, balsa strips 1mm thick and 7mm wide. These increase the bonding area of the covering film.

Fig. 27 - Wing manufacture (6).

8 – Finally, after the drying process, apply the covering film across the wing [32]. This film adheres to the balsa through the application of heat with an covering film iron [33].

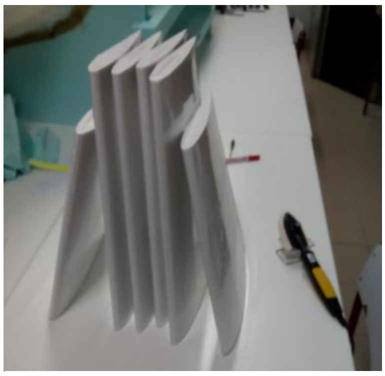


Fig. 28 - Balsa wings manufactured (7).

3.3.2 Prototype 1.5 - wings fittings

The support structure of the wings in the prototype 1 was heavier than possible, and so it was necessary to develop a new engagement structure for the new wings.

This structure also aimed to change the wing sweep. Thus, the designed wing's support structure is as shown in Fig. 29.

Fig. 29 - Control surfaces support

This set was designed to allow the fitting of the wings of the prototype 1.5 as the fitting of the rotors on prototype 2.5.

Its operation is very simple. It has two separate components that allow increasing the contact area with the blimp, making this a more stable mechanism with less risk of fall or change of form. One of these components has a compartment where the servo, or the rotor support tube, was placed. This component have free horizontal movement, allowing the modification of the wing swept.

A construction option was the printing of parts through a 3D printer using PLA (Fig. 30). It was a relatively easy and quick construction process without the need for manual labor.

Fig. 30 - PLA support structure

After 13 hours, the support parts have been printed. The material used was PLA and the print result shown to be slightly defective, in addition to the set of pieces was heavier than expected, about 44.3g in total (Fig. 30).

Due to imperfections of the components, it was necessary to sand them internally to be able to fit the Servo and the rotor metal pipe.

Despite this support piece is mechanically robust, did not fulfilled the most important requirement, low weight, thus resorted to the more traditional construction method using wood.

To make the new support parts, were used plywood plates. The shape of these layers have been cut by a laser machine. Then all the pieces were glued with cyanoacrylate. It can be seen, in the final assembly of the support part (Fig. 31).

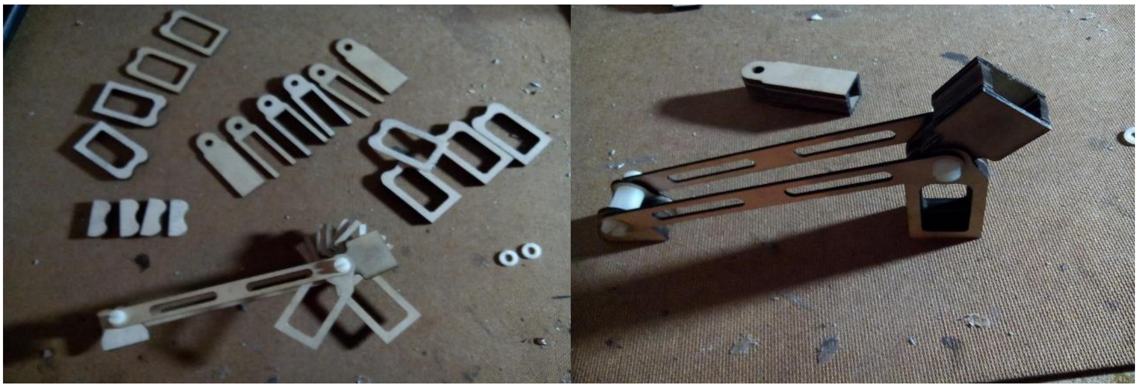


Fig. 31 - Wood support structure

The cut process of the parts, and gluing, took less time than its printing by the previous manufacturing method, however, the drying time, about 24h, increased manufacturing time. On the other hand the weight of the support piece was about 29.7g, much lower than the previous value. Thus, we chose to use the wooden support pieces because, despite its method of manufacture is more complex and time consuming compared to 3D printing, the weight difference was substantial.

To attach this support structure to Blimp, it was decided to glue the contact components to flexible carbon strips. These strips were cut from a laminated carbon fiber plate as it was previously explained in section 3.2.1. Then, the carbon strips were glued to EVA to not put carbon in direct contact with the Blimp (Fig. 32).

Fig. 32 - Attachement of wood support

The servo was placed within a docking component of the support piece, and a wooden plywood profile was applied. These profiles were then glued to the wings (Fig. 33).

Fig. 33 - Collage of fitting profiles among Servo and wing

Finally, the servo fitting component was screwed to the support part with plastic screws.

To reinforce the supports tensioners were placed between the wing and the blimp. These were carbon wire and were bonded to the balloon with adhesive velcro tapes. On the wing, the tensioners were fixed into the external rotation axis. Fig. 34 shows the blimp during test flight with wings and fittings mentioned above.

Fig. 34 - Adaptated Blimp realizing stability and control tests

3.3.3 Prototype 2.5 - rotors fittings

To support the rotors, the same method has been used for fitting the wings foregoing. The only difference was that at structural level, in the supporting parts, the servo has been replaced by a square tube used for fixing the rotors.

Each rotor was bolted to a square metal pipe. The other top was glued with hot glue into its slot which was coupled to the support piece (Fig. 35). For a greater structural strength, were placed clamps around the set of embedded parts.

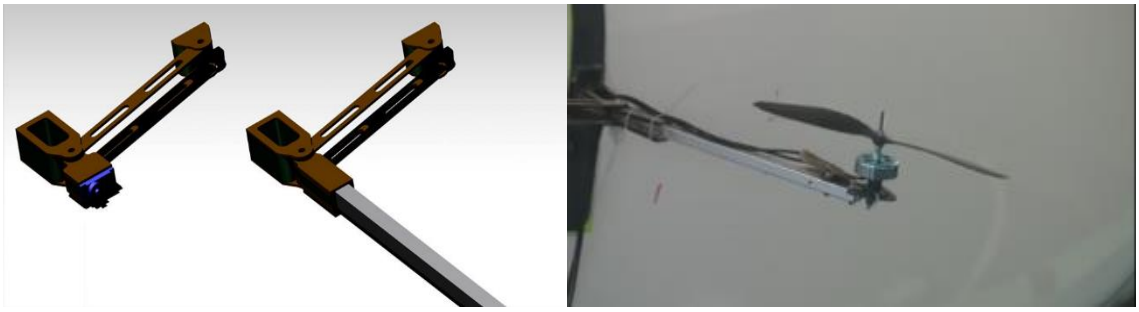


Fig. 35 - Rotor's fittings

3.4 Conclusion

As previously mentioned, the work of this chapter was not the main objective of the current dissertation however, without the adaptation of the blimp, would not be possible to determine the validity of the researched construction techniques to apply in Prototype 3. So it was important to document all the work made.

The applied solutions were viable, and so it was possible to make the flight tests required for the validation of concepts of another dissertation [30]. Therefore this purpose was concluded successfully.

Finally, all the work invested in the adaptation of the blimp turned out to be very time consuming, jeopardizing the start of the tasks of the next chapter that was the main goal of this thesis.

4. Prototype 3 – Manufacture methods

4.1 Introduction

After the consolidation of knowledge and concept validation through tests performed with the prototypes 1, 1.5, 2 and 2.5, we proceeded with the planning of the construction of a real scale prototype of 'Urblog'. To this has given the name Prototype 3.

Within this planning, it was necessary to test the best construction methods for structure and gasbags in addition to the assembly jigs design.

It was previously established that the material used for the structure would be carbon composite, but as for the material for the gasbags construction, had not yet been made any study. Therefore, this chapter includes the best method for the construction of the structure and a brief study and tests to find the best material for gasbags.

For the development of all components it was also necessary to develop appropriate construction and assembly tools.

Therefore, the aim of the study discussed in this chapter was the development of building tests of some components so, that time consume and building quality, of Prototype 3, were optimized.

4.2 Gasbags manufacturing

Its known that in the latest rigid airships, the materials used for the construction of gasbags are manufactured using the latest technology. It must be lightweight, durable and especially the least permeable as possible, so there is no loss of sustainer gas. The operation of airships becomes more expensive, due to gas losses, and this makes the investigation of materials to this component of extreme importance on project [34]. Thus, because the research for new materials is so expensive and valuable, there is no literature available about these materials and construction techniques.

However, the gasbags designed in this dissertation concerns a prototype (Prototype 3) for conception testing, and not to the final project, the requirements are not as demanding in terms of construction.

4.2.1 Gasbags materials

As previously mentioned, the choice of materials to use in the gasbag is very important for a proper operation of the prototype, without sustainer gas leakage. For Prototype 3, the chosen sustainer gas was helium, and there are few fabrics that have a low permeability.

The most efficient fabrics are composed by layers of different materials that meet gas retention, weathering/environmental protection and endurance requirements [1] and are made according to the project in which they are inserted. Therefore, they undergo a detailed research that translates into a great cost.

Regarding gasbag project that will be used in Prototype 3, it is not possible to study the creation of a new film suitable for the operation on this prototype, because it would be expensive and time consuming as well as no hand labor or appropriate infrastructure to create new laminates are available. Thus, this study is restricted to the fabrics available in the market.

Despite this condition, the material that will be chosen for the construction of Prototype 3's gasbags, have to meet some requirements, which are as follow:

- Low cost;
- Lightweight;
- Low helium permeability;
- Easy and fast manufacturing;
- Easy maintenance;
- Resistance.

These requirements are similar to those required by enthusiasts of homemade Blimps building. Therefore material research was made according to what is commonly used by them. Usually, the most common material spoken in specialty forums was 'Mylar foil'. This is the used term, that is actually polyamide laminated with a heat sealable layer of polyethene. The genuine Mylar® is a DuPont's trade name for its polyester film and this one is not heat sealable [26].

The research done to order the material referred to *Mylar Emergency Blankets*, also used for the construction of Blimps. Although, it is commonly named 'Mylar', this is not the correct term since, as previously mentioned, the polymer used was not manufactured by Du Pont, but the material was polyester also. In conclusion, it is incorrectly used the term 'Mylar' for a variety of materials, therefore this made research quite complex.

It was ordered a *Mylar Emergency Blanket* to undertake construction and permeability tests. This material was cheap, fulfilling one of the design requirements. After the arrival of the material, this was tested for the weldability, and, as it was composed by polyester, this could not be joined by heat. However, this material was suspended until it is found a new way to join it together.

During the materials research, was also discovered one fabric manufactured by a German company, LANITZ-MODELLBAU, the ORACOVER® AIR. This was a metalized polyester fabric suitable for Blimps constructing [32]. This had a various range of materials, and ORACOVER® AIR MEDIUM was chosen. The company also provided the ORACOVER® AIR Adhesive to make the unions since this material was not heat sealable. This fabric was more expensive than the last one.

The aim of this study was, mainly, to determine the best construction method, and for that it was necessary to find a material that was heat sealable, to make the comparison. A material used for enthusiasts of this area, as previously mentioned, was a laminated polyamide with polyethylene. So, was made the research for suppliers and the only ones that were found, are from the United States of America. They failed to respond to requests for information. Because this material was not available, similar material was looked up for solutions that enable welding. Thus, we met the laminate LDPE/PET-MET/LDPE.

There is no information that this fabric is used for the construction of Blimps, but given that the main aim of this study is to find the best construction method, use LDPE / PET-MET / LDPE, a fabric made of Low Density Polyethylene and Metalized Polyethylene Terephthalate, allowed to establish the procedures of construction in the case of heat sealable materials.

Therefore, acquiring these materials was mainly to study the best construction methods and to do a brief investigation about their permeability.

4.2.2 Manufacturing tests

The main objective of this study was to look for the quickest and most effective way to build gasbags. It was, available for testing, three materials. Two of them usually used for building envelopes Blimps, where the joint couldn't be weld, and another that would enable to evaluate the construction method by welding.

- **1º Manufacturing Test using *ORACOVER® AIR MEDIUM***

After a close reading of the manufacturing procedures, the construction of a small rectangular balloon was elaborated to train the construction method and refining its difficulties.

In the current test, was done a small rectangular balloon, in order to facilitate the couplings. The size of the balloon was chosen randomly. The construction procedures were as follow:

1. Outline the balloon shape. Cut with a sharp blade. Repeat and cut other part with the same shape.

Fig. 36 - Template cut

2. With the aid of a brush, apply ORACOVER® AIR adhesive on the edges of one side in both parts. Note the gas inlet opening and not apply the adhesive. Allow it to dry.

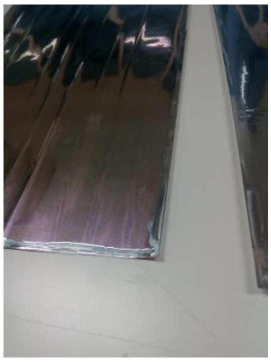


Fig. 37 - Adhesive application

3. Glue the two parts and applying heat with the aid of an iron in all the edges containing adhesive until it be completely united, except the gas inlet opening.

Fig. 38 - Finished Balloon

Following the construction of the balloon, the same was filled with air and when the inside air limit was reached, some of the bonding areas went loss, and in other areas the material ripped itself. As seen, this construction method did not show good results. So instead of a single bonding was decided to perform a double bonding.

- **2º Manufacturing test using *ORACOVER® AIR MEDIUM***

On the second test with ORACOVER® AIR, it was decided to make a balloon with the largest dimensions, about 58.5 cm x 70 cm not including the excess material from the gas inlet opening. In this test was used the same tools and the same material cutting procedure, but in a more careful way. The edges were outlined with white board marker with approximately 2 cm thick, and the adhesive was placed within these limits (Fig. 39). Once dry the two pieces were overlapped and glued. A margin of 2 cm from the edges of the faces was outlined again. It was placed adhesive in these margins (Fig. 40) and, after drying, the edges were bent (except the side of the gas inlet opening) causing the double bonding. The double bonding, thus was 1 cm wide.

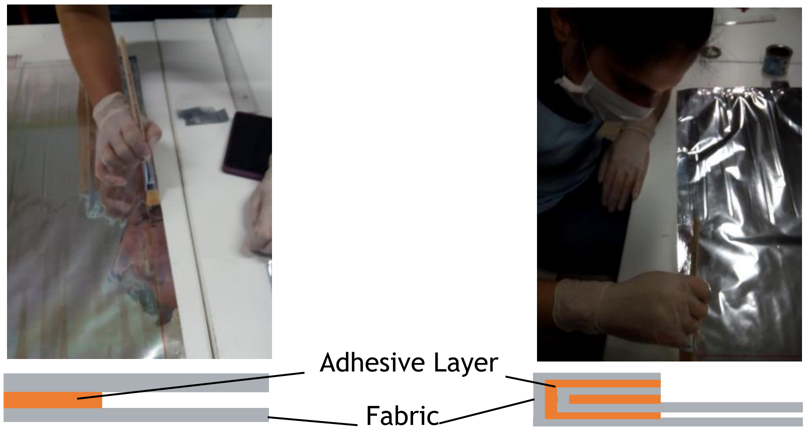


Fig. 39 - First Bonding

Fig. 40 - Second bonding

At the edge of the inlet opening was not possible to fold, so were bonded with the same procedure, two rectangles of the same material with a width of 4 cm at the ends, so as not to cover the opening (Fig. 41- Bonding B). First, only a margin of 2 cm of each rectangle was glued on one face, the remaining 2 cm wide, folded after the parts, have been glued on the other side. Fig. 42 and Fig. 41 illustrate the bonding of these reinforcing elements.

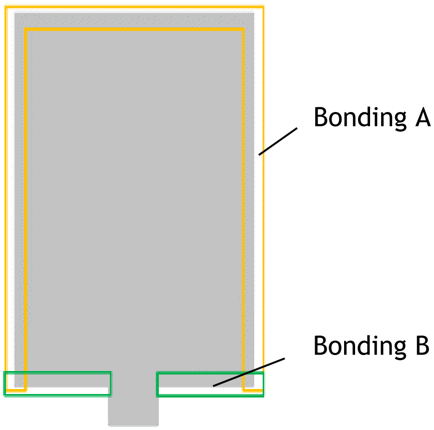


Fig. 42 - Different bondings allong the balloon

Fig. 41 - Reinforced Bonding

After the construction, it was filled with air. The result was not guaranteed in accordance with the supplier, the film ripped in some areas as we can see in Fig. 43. It was not possible to measure the internal pressure, but air supply was not forced, then the internal pressure that was applied, was the minimum acceptable that the fabric would hold.

This test could not establish if the cause of the bad results was the construction method or a defect of the material itself. Assuming that the construction method is not suitable for this application, new solutions were found.

Fig. 43 - Fissure after filling balloon with air

- **3º Manufacturing Test using *ORACOVER® AIR and Metalized Polyester film***

Since the previous test had a bad result, the new solution was the union of faces with tesa® Flooring Tape Extra Strong Hold. Using this adhesive was possible to test the construction method in two materials ORACOVER® AIR and Polyester fabric (Mylar Emergency Blanket).

In this test it was build two balloons, each with one of the fabrics. Measurements were both approximately 58.5 cm x 70 cm, without the material for the gas inlet opening, as in the previous test.

It was made the same types of bonding, single and double (Fig. 44), but with the new patch. Therefore, the cutting procedure was the same, regarding the bonding, it was necessary to apply the *tesa® Flooring Tape Extra Strong Hold*, which was previously cut with the appropriate measures, without requiring application of heat.

(a) (b) (c)

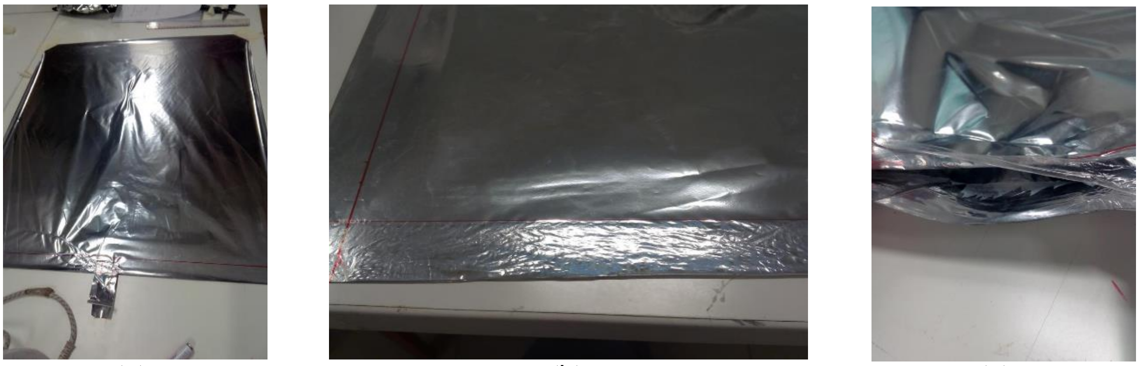
Fig. 44 - Manufacture test with the application of tesa® Flooring Tape Extra Strong Hold into two different fabrics. (a) Single bonding; (b) Single bonding balloons; (c) Double bonding

As the balloons build with single bonding, this proved to be insufficient because, after filling with air, the bonding separated itself. However, with the double bonding, both balloons had an excellent behavior after being filled with air. Bonding areas did not separate itself and there were no ripped areas.

- **4º Manufacturing Test using LDPE/PET-MET/LDPE**

This material enabled the welding joints by applying heat with an iron. Balloon measures, the cutting procedure and preparation of the material were the same as the previous tests. As for the bonding, were made two, first simple bonding and then double bonding. The bonding procedure was the same, obviously without the addition of adhesive, this was replaced by the addition of heat through a covering film iron [33] (Fig. 45a,b).

After building the balloon with the first bonding, it was filled with air, and after some effort to fill as much as possible, some welded points opened as shown in Fig. 45c.



(a) (b) (c)

Fig. 45 - Manufacture test with LDPE/PET-MET/LDPE. (a)Preparation of the material; (b)Welded joints; (c) Welded point that opened

It proceeded then to double bonding, folding the edges and applying heat again with the iron. Filled the balloon with air and insisted by increasing the internal pressure, resulting in the best performance without opening cracks.

- **Manufacture tests conclusions**

The last test proved to be the most easier and faster to execute. The fabric used in this test was LDPE / PET-MET / LDPE where double couplings were welded. The results after filling the balloon were very positive. The balloon had a high strength and did not open any fissure.

The gasbags' shape is round and this detail makes it difficult to build, in addition to the considerations foregoing, the conclusion is that the recommended materials to the construction of 'Gasbags' Prototype 3 should be 'heat sealable'.

In this study the main aim was to find a fast and easy construction method for the manufacture of gasbags, therefore running tests in different materials. But the requirements of a gasbag go beyond their ease of construction, this material also needs to have a low permeability to helium. As for the material used for the tests, LDPE/PET-MET LDPE, there is no information of using this laminate on Blimps or gasbags construction, so there was the need to test the permeability of this fabric to helium to check his behavior when exposed to the gas.

4.2.3 Permeability tests of LDPE/PET-MET/LDPE

The material that allowed the better construction was the LDPE / PET-MET / LDPE, concluding that according to the available conditions (space and labor), the material that should be used in gasbags must be heat sealable. It is known that, according to the analyzed state of the art that, the polymer Polyethylene has been used in envelopes building, and this one has a fair permeability. However, as mentioned above, there is no information of the use of the laminate LDPE/PET-MET/LDPE in gasbags or homemade Blimps, then it is useful to know the permeability of the same.

This material is commonly used in the food industry, and therefore was not subject to the helium permeability tests by the manufacturer. Entities that do this kind of testing were looked for, but without success. Then, the solution would be to calculate the permeability of this laminate according to the state of art, however it was impossible for lack of information of the material itself and the appropriate measuring tool were not available. Thus, it was decided to perform a small test, very simple, just to know the percentage of helium volume that the constructed balloon lost. It was known that the results relating to this test could not be directly represent the exact volume that a gasbag in real size would lose, but allowed to verify if the LDPE/PET-MET/LDPE laminated had a low or high permeability. The test was as follow:

1. Weigh the empty balloon done previously for the construction tests;
2. Fill the balloon up with helium;
3. Weigh the balloon;
4. Weigh again, after 72 hours.

As the volume of helium was not sufficient for buoyancy, it was possible to weight the balloon after filling.

The weight of the empty balloon was approximately 0.0749 kg. The difference between the weight of the balloon filled with helium and the empty weight was calculated at the beginning (t_0) and after 72 hours (t_{72}). This difference was related to the mass helium could held.

Table 5 – Total mass and mass lifted by helium during the 1st test

	Total Mass (Kg)	Mass lifted by helium (Kg)
Balloon filled with helium (t_0)	0.0315	0.0434
Balloon filled with helium (t_{72})	0.0402	0.0377

Now, it was possible, through the buoyancy force of helium, calculate the volume lost.

The buoyant force (F_B) was calculated by [35]:

$$\mathrm{F_B} = (\rho_{\mathrm{air}} - \rho_{\mathrm{gas}}) * \mathrm{g} * \mathrm{V} \tag{5}$$

Where F_B is the Buoyant Force (N), g is the gravitational acceleration ($\approx 9.8066\ \mathrm{m/s^2 or}\ N/kg$) and V is the volume (m^3) and $(\rho\mathrm{air} - \rho\mathrm{gas})$ is the difference of densities.

It is known that to calculate any force:

$$F = m * a \tag{6}$$

Where, m is the mass (kg) and a is the acceleration (m/s^2). In the case of F_B, the mass that can be lifted by a gas in air is:

$$m = (\rho_{air} - \rho_{gas}) * V \tag{7}$$

In the case of the lifting gas being helium, it is known that at sea level and at 15°C, $\rho_{He} = 0.1696\ \mathrm{kg}/m^3$ and $\rho_{air} = 1.2257\ \mathrm{kg}/m^3$,[36] so the amount of mass that can be lifted by helium in this conditions, for $1m^3$ is:

$$m = (1.2257 - 0.1696)\mathrm{kg}/m^3 * 1m^3 = 1.0561\ \mathrm{kg} \tag{8}$$

To calculate the helium volume inside the balloon:

$$Volume\ de\ hélio = \frac{\text{Mass lifted by helium in the balloon (kg)}}{1.0561} * 1m^3 \tag{9}$$

The helium volume inside the balloon at t_0 e t_{72} were:

Table 6 - Volume of helium inside the balloon at t_0 and t_{72}

Testing Time	Volume of helium inside the ballon (m^3)
t_0	$4{,}109 * 10^{-2}$
t_{72}	$3{,}386 * 10^{-2}$

The percentage of helium volume lost is giving by:

$$\%Lost\ Helium\ Volume = \frac{V_{HE(t_0)} - V_{HE(t_{72})}}{V_{HE(t_0)}} * 100 \tag{10}$$

After 72 hours, the loss was around 20%. If this percentage is divided by the three day trial, the balloon lost on average 6.7% of helium per day. But it is not correct to make this division, because the loss is not constant throughout the day, it depends on the internal pressure. To validate this hypothesis, it was made a new test with a duration of 48 hours. This test was similar to the previous, however the masses were measured at the start and every 24 hours. The results are shown in the following table:

Table 7 - Percentage of helium lost during the 2nd test

<table>
<tr><th>Testing Time</th><th>Volume of helium inside the ballon (m^3)</th><th>Percentage of helium lost (%)</th></tr>
<tr><td>t_0</td><td>$4{,}024 * 10^{-2}$</td><td>14.59</td></tr>
<tr><td>t_{24}</td><td>$3.437 * 10^{-2}$</td><td rowspan="2">3.86</td></tr>
<tr><td>t_{48}</td><td>$3.305 * 10^{-2}$</td></tr>
</table>

The results of the previous table shows that the helium loss is not constant during the days. The helium loss increases with the internal pressure increasing.

These results were compared with the value of helium loss of the Blimp used in the previous chapter. The loss of helium, per day, of the PVC Blimp is 0.3% [37], which is far below the results of LDPE/PET-MET/LDPE balloon. So, it is concluded that this fabric is not ideal for the manufacture of the gasbags of Prototype 3.

The access to LDPE/PET-MET/LDPE fabric was only guaranteed after the manufactured tests with ORACOVER® AIR Medium and Metalized Polyester film had been carried out. Therefore these ones were subjected to the permeability tests too. As constructive test in LDPE/PET-MET/LDPE material were the best, and also had better results in terms of permeability, only the tests performed with this fabric were taken in account. The results of permeability tests of the other fabrics are in Annex 1.

4.2.4 Gasbag manufacturing method using heat sealable fabric

From the previously performed tests, it was decided that is advisable that material the material used in Prototype 3's gasbags should be heat sealable. The material that was available was not suitable due to their poor permeability properties, however this would allow ascertain the best construction method for the construction of a gasbag.

The gasbag manufacturing referring to the section between frames 3 and 4, as these would also be built on this work, and the shape should be approximately the shown in Fig. 46.

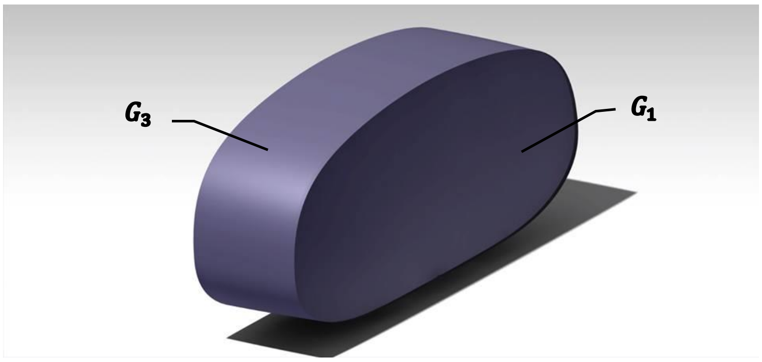


Fig. 46 - Gasbag nomenclature

It was decided that the two tops would be equal, to make it easier to build, so that a single part would join them together. For a better understanding of the construction method the tops were called, G_1 and G_2 and the union piece, G_3, as shown in the picture above. To proceed with the construction of the gasbag it was necessary a large space, because this piece is about 1.4 x 3.15 x 1m. As for the necessary materials and tools, that were as follows:

Table 8 – Materials and tools for Gasbag manufacture

Materials and tools	
Covering film iron	Red felt pen
Heat Sealable (LDPE/PET-MET/LDPE) Material	Sharp-blade
Welding Jig	Brown Tape
Wood stick	-

The welding Jig mentioned in the table above, it was a tool developed to support the welding. This consists of a table in which is attached a structure containing two metal 'T's with an upper bearing in wood. This wooden support allows us to have an ideal area for welding the components. The two 'T's are separated with the same width of the internal boundaries of the piece G_3. The Fig. 47 illustrates more clearly, this welding tool.

Fig. 47 - Welding Jig

In this construction, the templates of the tops were related to the internal shape of the smallest frame. In this shape, were removed 5cm, to have a gap between the frame and the gasbag after assembling the set of structural section with the gasbag. This template was printed on paper and cut out then.

The LDPE/PET-MET/LDPE fabric available was in a roll with about 1m wide, then to each peak, were welded four strips of this material in order to make a rectangle with about 4 m wide. After building two rectangles of material, the procedure was as follows:

1. Overlap the template in the rectangle material and secure it with tape. Outline the format with felt pen.

Fig. 48 – Gasbag manufacturing procedure (1)

2. Outline the format again with 10cm out.

Fig. 49 - Gasbag manufacturing procedure (2)

3. With a range of 10 cm from each other, write a number, starting at the center lower part of the template.

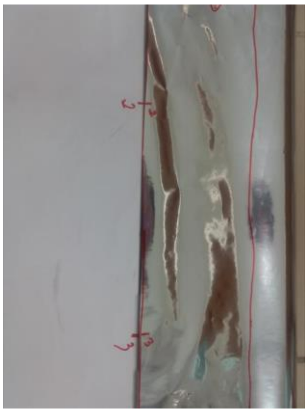


Fig. 50 - Gasbag manufacturing procedure (3)

4. Cut the outer shape. (In this construct a wider margin was cut, but it was concluded that there is no need). Again repeat the previous steps and to make a piece with the same shape, G_2.

Fig. 51 - Gasbag manufacturing procedure (4)

5. Place the G_1 and G_2 parts inside the welding jig with the delineated face turned inwards. Turn the outlined margins to support in the corresponding supports on each side and start with the marking 1.

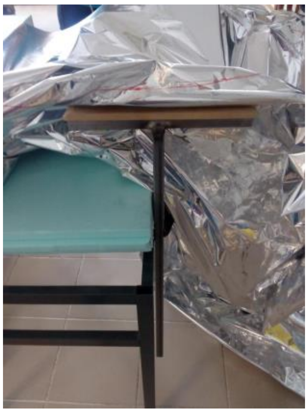


Fig. 52 - Gasbag manufacturing procedure (5)

6. Pull the roll of material of the piece G_3 and mark a line with 5 cm thick.

Fig. 53 - Gasbag manufacturing procedure (6)

7. Overlap the edges of the piece G_3, with G_1 and G_2 over the 'T' parts of the welding jig. Overlap the lines of the edge of part G_3 with the corresponding internal line of G_1 and G_2. Start welding with the iron the joint edges G_1+G_3 and G_2+G_3. Fold the 5cm surplus and do a double weld. Do not forget to leave an excess of part G_3, before start welding.

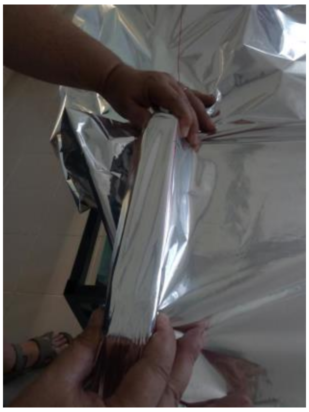


Fig. 54 - Gasbag manufacturing procedure (7)

8. After welding about 10 cm long on each side, pull the pieces in order to support, in the welding jig, the new edges not yet welded. Repeat step 7 until there is no edges for welding while taking in account the numbers previously written so that all the parts are welded correctly.

Fig. 55 - Gasbag manufacturing procedure (8)

9. To conclude, overlap both ends of G_3, piece, place a clapboard between each other (to make the gas inlet opening) and weld with the iron.

Fig. 56 - Gasbag manufacturing procedure (9)

After all welding operations are completed, the balloon was filled with air ((Fig. 57) and found out about the existence of holes on edges. This inspection was made through brushing water and soap, with a brush, in all inner edges of the welds. If, when bruising soapy water, bubbles appeared, this verify the existence of holes. These were easily covered up by the same material by welding it.

The construction method used proved to be quite viable, it was efficient, simple and relatively fast as expected. If the welding jig is built, and the template cut, the working time, according to the number of laborers necessary, is as is shown in the following Table 9.

Table 9 – Working time of gasbag manufacture

Task	Working time	Number of laborers
Preparation of the material (cutting, overlapping, welding) for further delimitation of the template. (x2)	3 hours	2
Delimitation of template margins (x2)	1hour 30 minutes	2
Cut (x2)	20 minutes	1
Installation of parts in jig	10 minutes	3
Weld the margins (considering that a person on each side welding the respective margin, another unfolding material, and providing logistical support)	3 hours 30 minutes	3
Weld G_3 piece margins	20 minutes	1
	= 8 hours 50 minutes	

The estimated time was not what actually was spent building the balloon, actually was almost doubled. The difference was due to lack of experience and time wasted looking for the best method. This estimated time takes in account the construction, according to the procedures advised done by experienced personnel. The result is shown in the Fig. 57.

Fig. 57 - Gasbag manufactured

4.3 Structure manufacture

The Prototype 3's internal structure materials and configuration was designed in another work involved in the same project, so the aim of the study for the current work is the search for solutions to make the best construction method.

After the structure is completely designed, it was possible to proceed with the construction of a section of the airship internal structure (two frames and related girders). This construction required advance planning, including the development of nomenclature and preparation of construction tools.

4.3.1 Nomenclature

Due to the complexity of components that the structure has, for an organized construction, it was required the naming of the components. These names made up by codes, are designed to make the construction easier, minimizing the occurrence of failures and working time. Then a nomenclature was developed for the total construction of the Prototype 3 structure.

Prototype 3’s structure is made up by 9 frames, which are interconnected by girders as shown in the following picture. The set of two frames interconnected with girders was called section. All these components are made of trusses and are therefore divided into smaller numbered pieces.

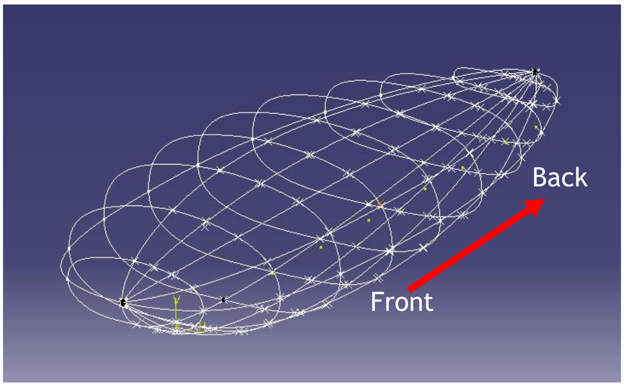


Fig. 58 - Prototype 3's structure

- **Frame's nomenclature**

Imagining that the available location for the building is small, the structure was divided into four parts, which were called Quadrants. The Fig 59 represents the division of a frame in front view.

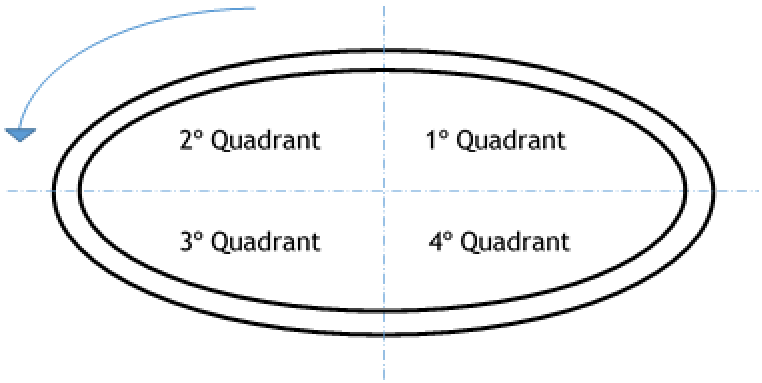


Fig. 59 - Frame quadrants

In the following Table 10 are the symbols given to each element of the Frame.

Table 10 - Element's Symbols of the Frame

Element	Symbol
Frame	**C**
Quadrant	**Q**
Type of Piece	**P**

Using the symbols above, it is possible to define a nomenclature to recognize and position each component in a quadrant of a frame. The simplified form is then:

$$CxQyPz$$

Where:

x, represents the frame;

y, represent the quadrant;

z, represent the type of piece.

As for the frame number, x, they must be numbered from front to back. The prototype has 9 frames altogether. The y, which is the quadrant number, indicates in which component is located. The z, refers the type of piece. Until the current design point there are the following types of components illustrated in the Fig. 60., as an example, shows the first quadrant of frame 3 (C_3Q_1).

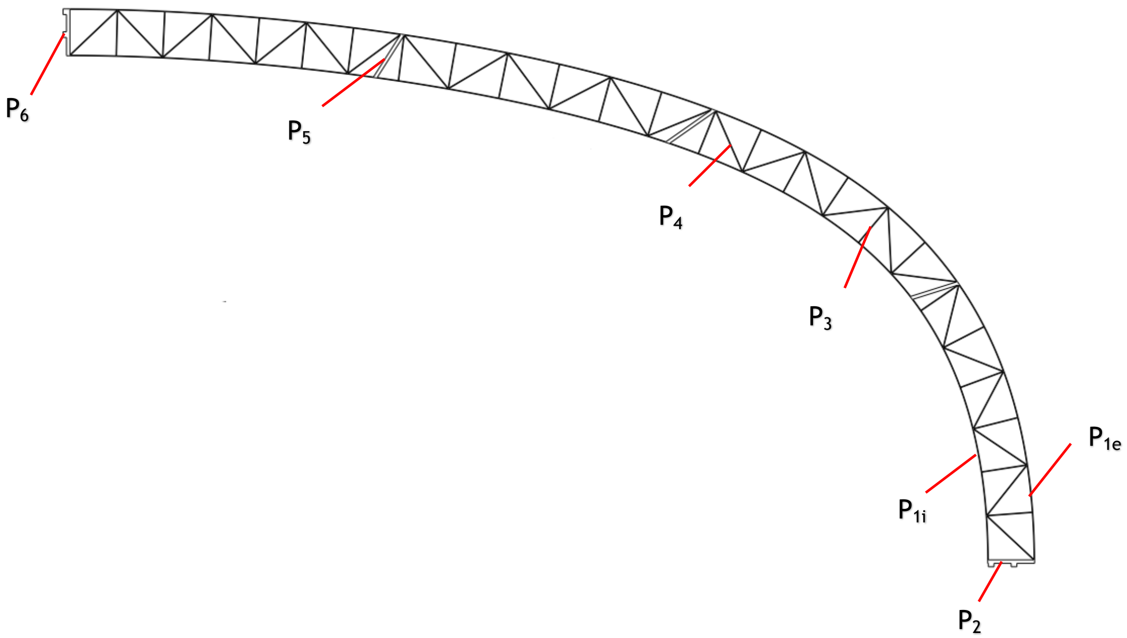


Fig. 60 - Example of frame's quadrant numenclature

The previous nomenclature gives us the component placement in a certain quadrant of a frame. If the exact positioning of the component is required, then the simplified form assigned previously, is able to be specified.

After defining the Frame and Quadrant where the component is positioned, can be added a number to the type of piece symbol, from the correct place. For a better understanding, the Fig. 61 illustrates the nomenclature of some randomly selected components.

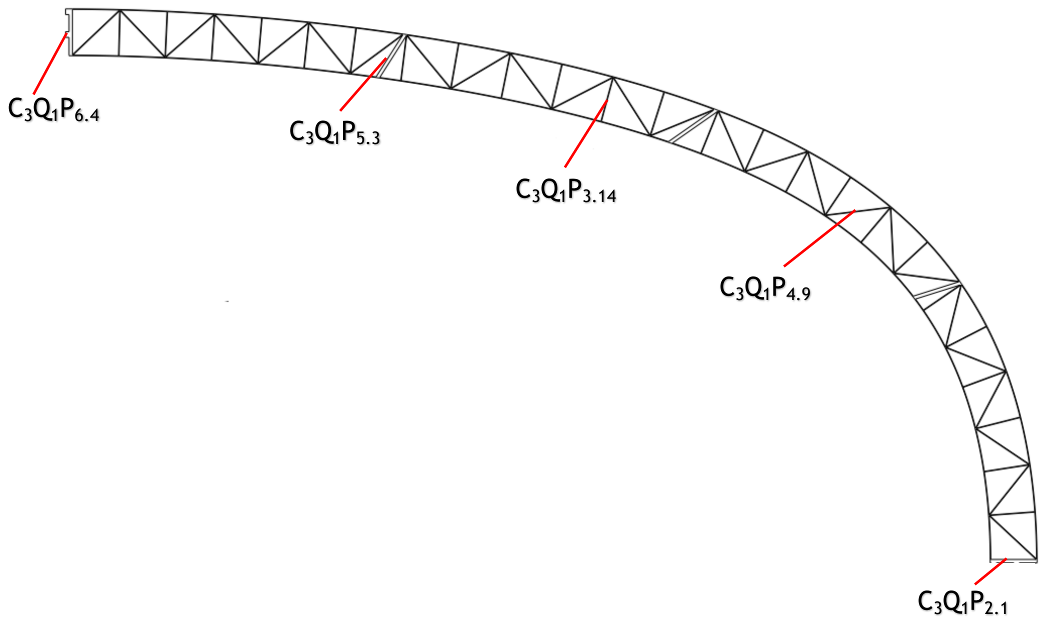


Fig. 61 - Some components nomenclature

Therefore, definition of the exact position of each component is generally given by the following nomenclature:

$$\boldsymbol{CxQyPz.t}$$

Where t indicates through a digit, the component position. This position, in each quadrant, starts to be numbered in the reverse clockwise direction and from the outside in.

This nomenclature is designed so that, whenever we need to change the project is easy to assign a new name or position to a component by applying a number in lower exponent.

For example, it is possible that some frames could be divided into two elements to facilitate the pre-assembly of the prototype sections before final assembly at the test site. So, the first element, provided by the direction in Fig. 58, is named as follows:

$$\boldsymbol{C_{1.1}}$$

The number given next to the frame symbol indicates the piece according to the direction established in Fig. 59.

- **Girder's nomenclature**

The reasoning used in the nomenclature of the girders is the same as previously in frames. So, the symbol $'L'$ was choosen to make reference to a girde. In simple terms to refer to the girder it was defined the following nomenclature.

$$\boldsymbol{C_{x/y}Q_zL_t}$$

Where:

- x/y, Represents that the girder is between frame x and girder y;
- z, Represents in wich quadrant is the girder placed. In some cases, if the girder is between two quadrants it should be named z/w. The w represents the other quadrant that share the same girder;
- t, Represents the number of the girder. This one goes from 1 to 16 and the numbered starts in the first quadrant.

The Fig. 62 show us some examples.

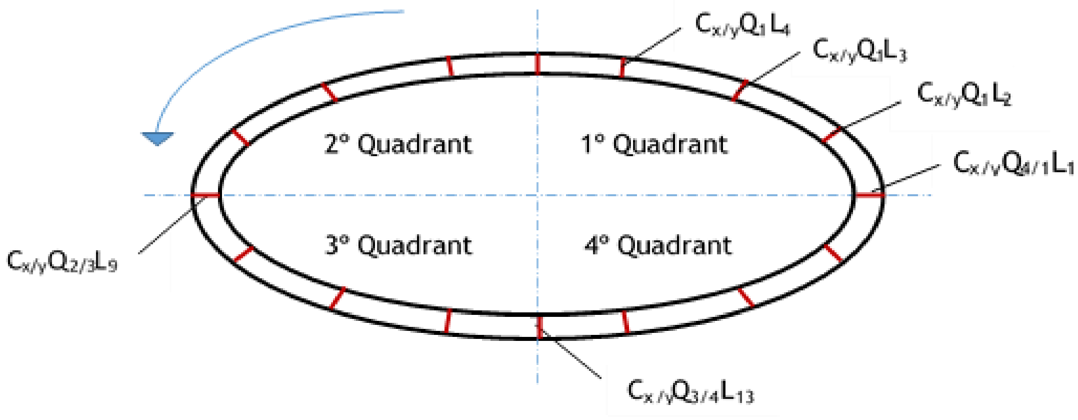


Fig. 62 - Example of nomenclature of girders between frames

As for the type of pieces, they will be illustrated in Fig. 63. It is taken in account that the girders in this picture are related to frame 3 and 4 and the first one is placed in the first quadrant 1 and the second one is placed between quadrant 1 and 4.

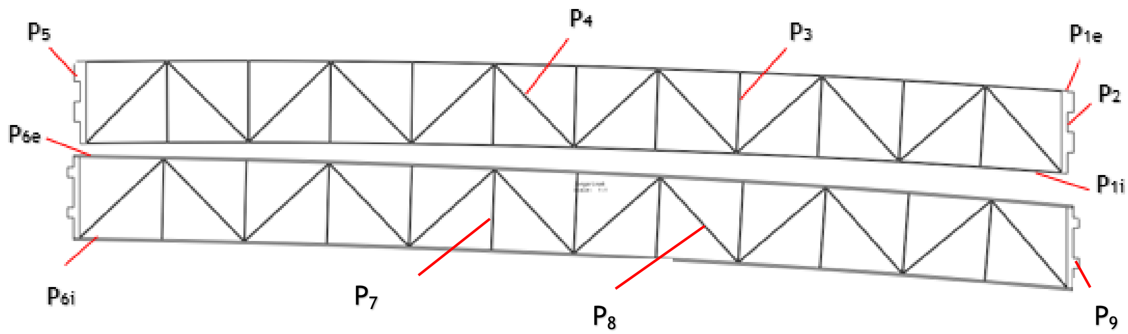


Fig. 63– Example of the nomenclature that was given to girders pieces

Thus, the position of each component is given as follows:

$$C_{x/y}Q_zL_tP_{n.u}$$

Where the n, represents the type of piece and the u it is the position, starting from the direction mentioned in Fig. 58. The same reasoning is explained previously for the positioning of the frames pieces.

4.3.2 Construction jig

After the nomenclature given to pieces, it was necessary to find a way to assemble all components in the appropriate place to be united later on. So, it was need to create a construction jig. The requirements for this tool, to be applied in the construction of a section of Prototype 3's structure, were low cost, reusability, ease and speed of development.

The construction technique chosen is the common for manufacturing wooden structures for airmodel, for example. Briefly, in the jigs used, is designed the template of the piece to build, then blocks are put around this layout to later on, fitting the pieces into the cirrect place to be glued [38].

These jigs are usually constructed of wood, however, in this work, the material chosen was extruded polystyrene. The choice was due to its very affordable cost, as well as the time that was available, for the construction of the section structure, was short and extruded polystyrene board allows to be worked quickly and conveniently without requiring access to the machines. The only tool needed was an sharp blade.

The material and tools needed to build this Jig are in the Table 11.

Table 11 - Material and tools used for jig's manufacture

Materiais e Ferramentas	
Boards of extruded polyestirene	Sharp blade
Transparent adhesive tape	Sewing pushpin
Latex gloves	Mask
Template printed on paper	

Thus, the construction site of frames and girders consists of an extruded polystyrene board with the printed layout of the part meant to be build, glued. Over the printing it is glued a transparent plastic film, so that the layout can be reused if necessary. Then, on top, are placed blocks from the same material, around the designed template. These blocks are previously cut from an extruded polystyrene board with an sharp blade, and becausesince they are a foam, are attached with pins allowing its reuse. The amount of blocks is not an exact number, as it must be according to the need that the components have to remain in the correct location. We have to keep in mind not to put blocks in the bonding areas.

Fig. 64 illustrate an example of a construction jig for assembling of a quadrant of a frame.

Fig. 64 - Prototype 3 section structure's construction jig

4.3.3 Manufacturing test 1- 1m truss

One of the objectives of the present work was to build a section of the frame of prototype 3. This construction has the purpose of finding the best construction method refleting the optimization of the manufacture of the final structure. It should be noted that, this construction was made in a moment of the project where the structure was not definitely defined, hence this construction does not mean that it has to be used in the prototype 3's structure. This was a construction made only to establish the difficulties of such a building, solutions to apply and the approximate time of manufacture.

The material of the structure had been previously chosen in accordance with another research work involved in the same project. Given the inexperience of construction with this material it was decided that it was appropriate to make a smaller constructive test, a small strip made of trusses with about 1m, which would also serve as a simulation of structural tests to validate theoretical data work mentioned earlier. After confirming the construction technique it would be possible to proceed with the construction of the section (two frames and 16 girders).

In this constructive test, the template with the shape of the constructed part was glued to the construction jig, and the assembly procedures, of this tool, were previously mentioned in a subchapter.

The materials ordered is standard, in strip format with 2m long, so the components were cut from these strips. The cut was made by hand with a suitable saw, but because this cutting surface had a large thickness, all components were cut with excessive extent in order to be subsequently sanded to achieve the precise measurement. After being cut and sanded, they were placed on the assembly template to be glued afterwards.

After all the components are in the correct locations, they were glued with cyanoacrylate. This bonding is provisional and allows withdrawing the part of the building jig to be worked in a more practical way. Then, after the glue dry, the piece was extracted. Removing the jig there were several components that have broken. After the piece was installed vertically, supported by some external parts of extruded polystyrene (Fig. 65). In this position, it became easier to make the final bonding.

Fig. 65 - Composite truss with 1m

Due to the contact area of the parts being so small, it was decided that all bonds should be strengthened with some piece that increases the bonding area. Thus were cut semicircles with 1,5 cm and 2 cm in diameter from a carbon plate, as explained in section 3.2.1, with two carbon fiber layers. Semi-circles with 2cm were applied at the point of interception of four components and the ones with 1.5 cm diameter were placed at the points of intersection of two components. A quadrant of circle was also cut with a radius of 1 cm to apply in the ends. To cut these pieces it was used an appropriate carbon fiber scissor. The fiber was covered with masking tape where it was designed, with the help of a mould, the circles with a pencil, to be cut latter. It is estimated that the implementation time for a person to cut 100 pieces is about 2 hours. At this pieces we called reinforcement parts.

Fig. 66 - Composite truss with 1m. (a) Reinforcement parts bonding with clothespins; (b) final piece after all parts bonded

Thus, while epoxy glue were applied, the components that peeled off were glued and the reinforcement parts were applied on both sides. The low ones were the first to be glued, and were fixed with wooden clothespins. After about half an hour, the glue applied was not so fluid so the piece was turned over, and the missing reinforcement parts were glued, fixing them in the same manner (Fig. 66).

These tasks were all made by two people. Due to the adhesive working time is low, all gluing work had to be done quickly and in a mechanical way. While a person applied the glue, the other applied reinforcements and fixing clothespin. This was a thorough job and more difficult than expected, it was not easy to fix the reinforcing pieces without them leaving the required position.

The end result was acceptable, but not perfect. The gluing quality fell short, as some of the reinforcing parts moved during the curing time of the adhesive. Some of them completely took off and had to be re-glued. Other peeled off but not completely, as shown in Fig. 67, and the bonding was very defective.

Fig. 67 - Defective bonding

After all the reinforcing pieces were glued in an acceptable way, external excesses were sanded ((Fig. 68).

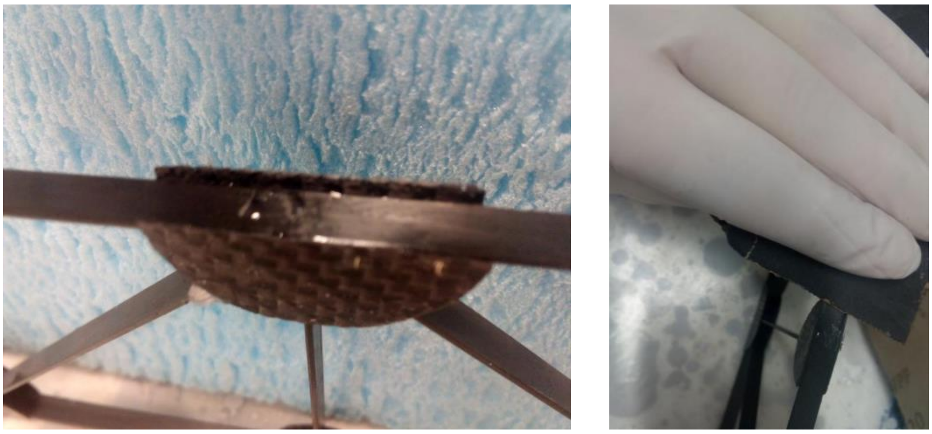


Fig. 68 - Finishing touches (final sanding)

Considering that there was no need for repairs, the approximate time of construction of this piece, with two people working at the same time is shown in Table 12.

Table 12 – Working time of 1m truss manufacture

Task	Aproximated working time
Total assembly of the jig	1 hour 30 min
Cut and place the pieces in the jig	5 hours
Bonding + cure with cyanoacrylate	15 min + 15 min
Bonding with the reinforcement pieces (bonding1 + waiting time+ bonding2)	15min + 30min + 15min
Cure time of the glue	24 hours
Sand the external structure	1 hour
	= 34 hours

Taking the glue curing time, the execution time is approximately about six hours. Indeed, given that it was necessary to repair the structure, the working time was superior, and it was necessary to wait again the cure of the new bonding. So for this structure to be finally ready it was necessary approximately 2 more hours and 24 hours of cure.

The main conclusions of this test were:

-The components cutting time was too high, and was decided that for a next construction the same would be cut by a cutting machine with a diamond disk. This cutting should have a small excess, and then through sandpaper, be suitable for the correct size.
-The cutting time of the reinforcing pieces was too high, it was therefore necessary to find a more effective method.
-Place the part in a vertical position to glue the reinforcement parts and using clothespins has shown not to be effective. Due to the gravitational force reinforcement parts moved from theirs position and pelled off and the force exerted from the clothespin also made the parts to stay loosely glued.
-Bonding work had to be done necessarily by two people.

4.3.4 Manufacturing test 2 – frames and girders

The biggest section was the one that it was decided to be built, i.e. the section which included frames 3 and 4 and associated girders. Since the room available for the manufacture of these pieces was small, it was necessary to divide the section into 4 parts that were called quadrant. Frames were built first and then the stringers. In this construct was used the nomenclature described previously. Also, for health and safety reasons, all jobs were done using gloves, mask and protective clothing.

- **Frames manufacture**

For the construction of each quadrant of each frame it was built an appropriate jig, as shown in chapter 4.2.2. In order to the components cut, to be faster, this was done with the help of a cutting machine with a diamond blade. It is estimated that the time for cutting and marking of all the components to use in one quadrant of a frame took approximately 1h 30min and this task is performed by one person and a cutting machine. All components were cut with a small excess only to be sanded until reach the ideal measure.

Regarding the reinforcing pieces cut with scissors took a long time, and it were not perfect, it was then decided to make two circular punctures with a diameter of 2 cm and 3 cm. Then, with the aid of a hammer, the reinforcing pieces were cut from the above laminated boards. Afterwards, these pieces were cut into two or four part, with scissors. Rectangular reinforcement pieces with 2cmx1cm were cut to reinforce the bonding of parts P_6 with parts P_2.

For the assembling and gluing procedures, along the construction, it was tested a great amount until it reached what shown to be more effective. In Table 13 are the materials and tools needed for the construction of frames, in accordance with the procedures previously mentioned. In this table, the materials and tools used in the construction Jig is not considered. Its construction was in accordance with section 4.2.2.

Table 13 - Materials and tools necessary for frames' manufacture.

Materiais e Ferramentas	
Permabond® ET515 Semi Flexible 15min Epoxy Adhesive 50ml Twin Tube [39]	Permabond® 50ml Twin Tube Cartridge Gun Dispenser [40]
Permabond® Static Mixer Nozzles for 50ml Twin Tube [41]	Carbon Fibre Strip 1mm x 6mm [42]
Mirka® P120 Waterproof Wet and Dry Abrasive Sanding Paper [43]	Pultruded Carbon Fibre Square Box Section 6mm (4mm) [44]
Cutting machine with a diamond blade	Toothpick
Plastic film	Perma-Grit® Sanding Block Small [45]

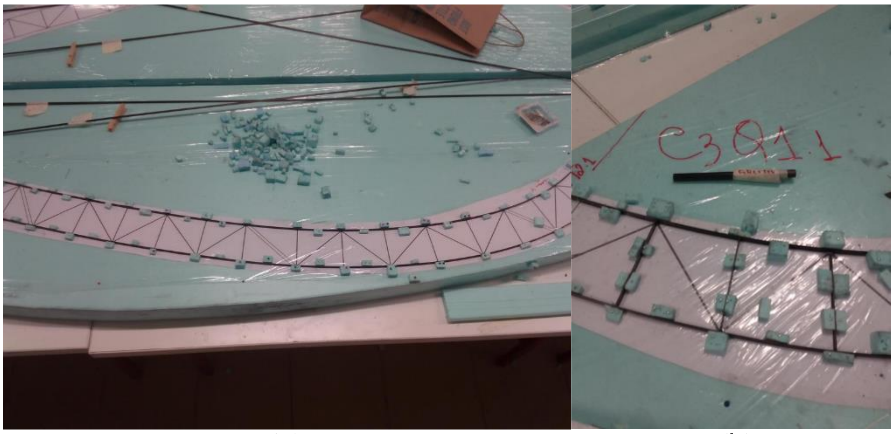
From the section that had been built, the materials used in each type of part from the frame were as follows:

Table 14 - Material used in each type of piece of frames

Type of Piece (frames)	Material
P_{1e} ,P_{1i} P_3 P_4	Carbon Fibre Strip 1mm x 6mm
P_2 P_5 P_6	Pultruded Carbon Fibre Square Box Section 6mm (4mm)

For the assembling of components on the building jig, the procedure is:

1. Place the P_{1e} and P_{1i} parts and rectify the size with sandpaper (Fig. 69a).
2. Place the P_3 parts. These are sanded one by one after placement to confirm its right size. As they are put in the right place, secure them with extruded polystyrene blocks (Fig. 69b).
3. Place the P_4 parts and proceed in the same way, from point 2, taking especial attention to make that tips had a sharp shape in order to increase the contact area. That improves the bonding.
4. Insert the P_2 parts and do the same from point 2.
5. Place the P_5 parts and do the same from point 2.
6. Place the P_6 parts and do the same from point 2.



(a) (b)

Fig. 69 –Structure's manufacture. (a) Procedure 1; (b) Procedure 2

After putting all the components in the correct locations, they were bonded. The use of cyanoacrylate glue was abandoned for this type of bonding because it is weak and does not allow an easy handling of the part. Throughout the construction of frames, some bonding procedures were tested, and showed that more effective way was as follows:

1. Apply epoxy adhesive in all contact points and spread with a wooden stick. (A person applies the glue, another distributes).
2. Wait for the epoxy adhesive to cure.
3. Remove the part from the assembly jig.
4. Move the part to a smooth surface previously covered with plastic film.
5. Place Epoxy Adhesive in all contact areas with the reinforcement parts and glue them. The epoxy adhesive must be spread with aid of wooden stick. (A person applies the glue, the other spreads and glues the appropriate reinforcement part.)
6. Turn carefully the part and wait for the glue to settle.
7. Do the same from point 5 in the new face and turn it.

8. Place an extruded polystyrene board to distribute the weight evenly.

After the bonding is cured, remove the part and check if all the components and reinforcement parts are securely. If there are parts that are not, repeat the bonding process.

9. If all components are well secured, glue in all P_5 parts the parts for the P_6 fitting system. After measure and mark the points where it should occur the bonding as defined in the structural project.

When the piece have all components glued, it must to sand, externally, all the excesses of the reinforcement pieces, carefully to not pull it off. This work can only be carried out by one person to the part.

It is difficult to define the working time required for completion of a quadrant of a frame, because during the work performed there were several setbacks, such as lack of material or conditions, but what held longer was repairing bad bonded parts. If one considers that the complete piece is completed smoothly and there is no need for repair, we can estimate the approximate time of construction of a quadrant of a frame made by two people with experience as follows:

Table 15 – Working time of a quadrant of a frame

Task	Aproximated working time
Build the jig completly	2 hours
Sand and install P_1 piece	10 minutes
Sand and install P_3 piece	30 minutes
Sand and install P_4 piece	30 minutes
Sand and install P_2 piece	10 minutes
Sand and install P_5 piece	20 minutes
Sand and install P_6 piece from the edges	5 minutes
Pre-bonding with Epoxi	10 minutes
1ª cure	24 hours
Reinforcements bonding (side 1)+wait time	30 + 30 minutes
Reinforcement bonding (side 2)	30 minutes
2ª cure	24 hours
Sand and bond P_6 piece on P_5	10 min
Sand the excess	1hour 30 minutes
	=55 h 05 min

The total estimated time considered that all components have been previously cut.

In the space available for this construction was possible to build two frames' quadrants, so this time could be optimized considering the time of healing of Epoxy Adhesive is the same for both.

- **Girders manufacture**

Regarding the building of the girders, the assembly procedures and bonding used were very similar to the ones from the frames. As for the materials it has been used another type of material beyond the Table 13, the carbon fibre strip 2mm x 12mm. In girders that were in the same quadrant was used the same material as for the frames. The girders that were between two quadrants, the carbon fibre strip 1mm x 6mm was replaced by carbon fibre strip 2mm x 12mm.

Briefly, the materials used in each type of piece of the girders were as follows:

Table 16 – Materials used in each type of piece of the girders

Type of Piece (Girders)	Material used
P_{1e} ,P_{1i} P_3 P_4	carbon fibre strip 1mm x 6mm
P_{6e} ,P_{6i} P_7 P_8	carbon fibre strip 2mm x 12mm
P_2 P_5 P_9	pultruded carbon fibre square box section 6mm (4mm)

The assembly of the components of girders which were in the same quadrant had the same procedure used in frames, for the girders, that were between two quadrants, the procedure was similar but with slight differences. Thus, the assembly of a girder between two quadrants, had the following procedure:

1. Place the P_{6e} e P_{7i} pieces and rectify the size with sandpaper (Fig. 70).
2. These are sanded one by one according to the right placement and have to be the right size. As they are placed in the right location, secure them with extruded polystyrene blocks (Fig. 70).
3. Place the P_8 pieces and do the same from point 2, taking care that the edges do a nozzle with 45 from both sides so that the contact area is greater.
4. Insert the P_2 pieces in the correct location. Put two P_2 pieces overlapping and do the same from point 2.
5. Place the P_9 pieces. Placing a support part below this one, so that it is perfectly centered between P_2 pieces

Fig. 70 - Girders manufacture

The bonding procedure, for both types of girders, followed the same reasoning used for the frames, so there is no need to be documented again. After applying the assembling and bonding procedures, it was possible to estimate the working time. For this, it is considered that all the components were previously cut in the cutting machine, with a diamond blade. As in the frames, this time is approximated and does not include repairs, it is considered that the construction was perfect and carried by two people.

Table 17 – Working time of girders manufacture

Task	Aproximated working time
Build the jig completly	20 minutes
Sand and install P_1/P_6 pieces	10 minutes
Sand and install P_3/P_7	10 minutes
Sand and install P_4/P_8	10 minutes
Sand and install P_2	20 minutes
Sand and install P_9	10 minutes
Pre-bonding with Epoxi	5 minutes
1ª cure	24 hours
Reinforcements bonding (side 1) +wait time	10 + 30 minutes
Reinforcement bonding (side 2)	10 minutes
2ª cure	24 hours
Sand the excess	30 minutes
	=50 h 45 min

This was the estimated time for making a piece, actually this was optimized. Since the space available allowed the construction of several girders, all assembly and bonding allowed in one girder must be done together then the curing time was the same for all. Since the time of construction and materials available in the current study were limited, it was only possible to build 8 girders.

4.3.5 Structure section assembly – fitting system

The fitting has been defined in structural design, in another work involved in the same project. In this system each end, of the frame's quadrants or girders, have two parts which fit together at another corresponding frame quadrant or girder's end. Then, they are locked by a square tube with the same internal thickness of fittings. For a better understanding, the Fig. 71 illustrates an example of a fitting system. After all frames and girders were perfectly constructed, it was possible to proceed to the final assembly. In this case, the assembly jig was not developed yet, then the assembly of all parts had to be done on the ground.

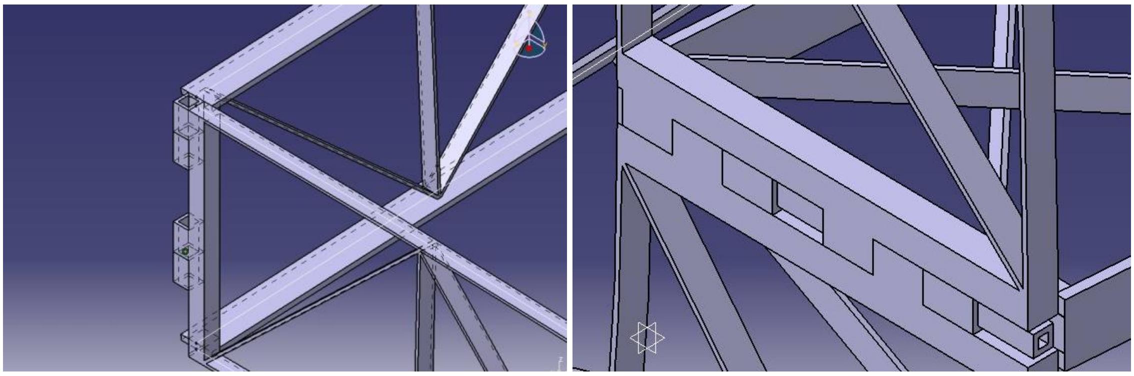


Fig. 71 - Structure's fitting system

Briefly, and not taking into acount all the difficulties that occurred, first the frames were assembled on the ground, then the girders were carefully placed in one frame and supported to remain in the correct place. Then the upper frame was placed and fitted (Fig. 72).

Fig. 72 - Assembly of structure's section

This assembly was more complex than was predicted because due to the fragility of the fitting pieces, many of them came off or broke. In order to achieve the final assembly, it was necessary to resort to duct tape and cable ties to reinforce all the fittings.

4.4 Assembling Jig

After the complete construction of frames and girders, is required a tool for their union. This tool is called Assembling Jig. All aeronautical constructions have tools of this type, which are designed according to the needs of the project. The construction of Prototype 3's structure is no exception. So, for a proper assembly, it is necessary to design an Assembly Jig that complies with some requirements stipulated by the working group of this project, such as:

- Low cost;
- Quick and easy manufacture and assembly;
- Simultaneously assembly, support and transportation tool;
- Ergonomic;
- Modular to facilitate transportation and its storage.

4.4.1 Conceptual design of an assembling jig

To fulfill the first requirement, low cost, the material chosen was extruded polystyrene. This one is cheap and easy to work, so also fulfill the second requirement too.

So, also agreement with other stipulated requirements, and considering that the frames will be built completely, undivided, the designed Assembly Jig is shown in Fig. 73.

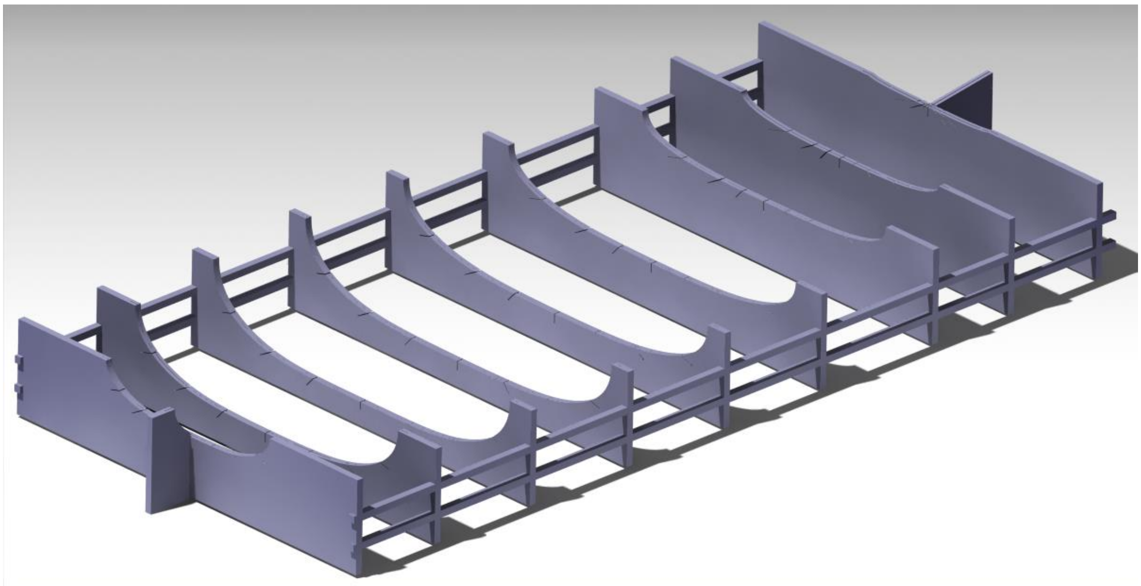


Fig. 73 - Complete assembling jig

Firstly, the assembling jig was sized in a way that when the airship is supported, the construction worker can reach the highest points. The height between the floor and the highest point of the airship over the assembling jig is about 1.80 cm.

This Assembling Jig is made of several components. Fig. 74 shows half of the Assembling Jig decomposed for a better understanding.

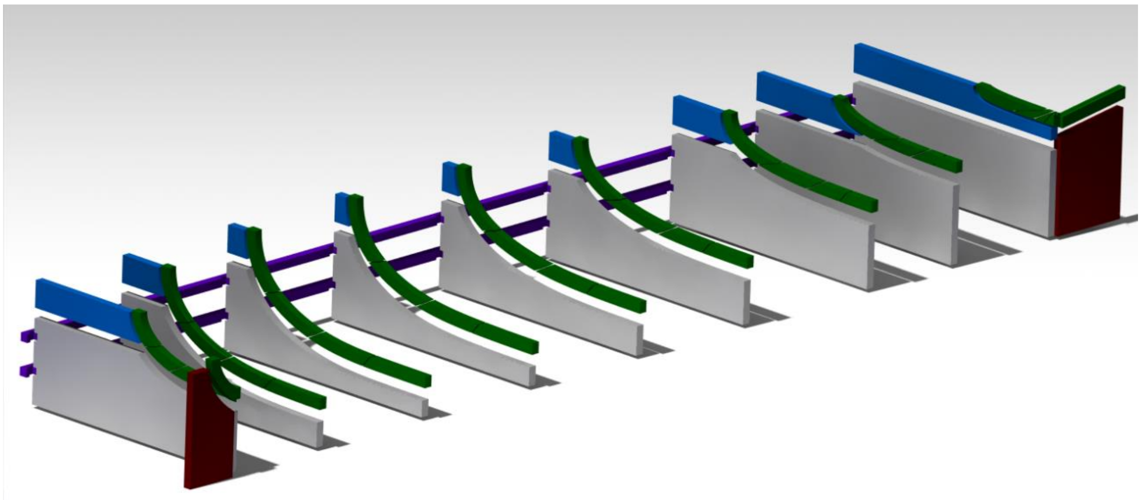


Fig. 74 - Exploded view of half Assembly Jig

(a) (b)

Fig. 75 - (a) Frames and girders attachment system; (b) Fitting system of support and longitudinal pieces

The gray pieces are the main part of the tool. They have the external shape of the frames, and are used to support these components. The maximum height is according to the standard width of the extruded polystyrene boards, 60 cm. Blue pieces that fit into the gray, complete the external shape of the lower frames. The possibility of remove these parts, allows the assembly of the wings. The green pieces are removable and are used to fix the frames and girders. These are made of several parts, which correctly placed on top of the gray pieces only have the necessary space to fix the structural components (Fig. 75a). The longitudinal pieces (purple) are used to fix the gray pieces in accordance with the measures between frames. The fitting system is shown in the Fig 75b. The red pieces support the front and rear structural parts in the same way as the gray ones.

As the material is a kind of foam, the fixing system of all the pieces can be done through wood sticks reinforcing the joint. Thus allows the removal of parts when needed. This tool is modular and can be adapted to the structure assembly needs. For example, if we only need to assemble one structure section, is not necessary assemble all the pieces that composes the assembling jig, only the required ones. For that, the only need is to adapt the longitudinal (purple) pieces. Regarding the transportation, the structure sections can be moved in the Assembly Jig, supported by the green pieces.

As this is a conceptual design, the technical draws, with the most important measurements, are in Annex 3.

4.4.2 Assembling jig modifications

The transportation means does not allow to move all the structure together, so if the assembly site is not the same as the flying tests site, it is necessary to divide it in sections for taking it from one site to another. In this case, could be necessary to divide the frame between transportation sections. Due to limitations of transporting means or working place, could be required to divide the frames into two halves. Therefore, the design of this assembling jig is conceptual and could be easily changed according to new requirements.

4.5 Conclusion

One of the objectives proposed in this dissertation was the search for appropriate materials for gasbags. This search proved to be more difficult than expected because there is almost no information about fabrics composition that are used in gasbags, so this demand was according to what is used in blimps envelopes made by enthusiasts in this area. Most of manufacturers and suppliers of blimps material, are usually in United States of America. Some of these manufacturers of fabrics used in blimps were contacted unsuccessfully, and others did not sent samples to Portugal. That is why it was not possible to test more fabrics.

Regarding the constructive tests, the fabric that had worse result was the less expectable. The ORACOVER® AIR MEDIUM was the only fabric of the three studies it was recommended for use in blimps envelopes and the method recommended by the manufacturer was not feasible. Due to the complexity of manufacture of fabrics that were not heat sealable and high gas escape probability by unions, abandoned the hypothesis of using such a material. The construction of the test laminate LDPE/PET-MET/LDPE proved that gasbags must be constructed by a heat sealable material.

The fabric composed of LDPE/PET-MET/LDPE was provided by a food casing producer, so had no information about its permeability to helium, that is why it was necessary to make a simple test to determine the percentage volume of helium lost in a small balloon. It is important to note that the tests were not intended to quantify the helium lost, but to qualify losses in general and the results showed that this material was more permeable than intended. This result was expectable because, so it was studied in the State of Art, the LDPE have fair permeability. According to the same study, probably a Nylon or PVDC fabric have better helium retention performance. Earlier, similar tests were done to other fabrics, but since the lost helium results was very high, did not even considered for this work, apart from that the construction method for both was not feasible.

Although it has reached the conclusion that the fabric LDPE/PET-MET/LDPE could not be intended for the gasbags manufacture, this was the only one available to test the manufacture method for building one gasbag in real size. Inexperience and lack of working space increased the manufacturing time compared with that actually needed. In general, the method used proved to be very effective, and if the procedure is carried out as explained, the construction of each gasbag will be fast. It was also necessary to develop a gas inlet and retention's system for gasbags, but this has not been possible because there was no time available for that.

About the structure, due to the complexity of all components, it was necessary the development of nomenclature. This allowed that the construction follow an organized manner reducing the possibility of errors.

To assemble all the components it was developed a construction jig, according to what is common in this type of manufacture. In this case the material of this tool was extruded polystyrene and not wood, as well as being cheaper, was quick to be cut and the same board could be used for various constructions. However, as it is a foam, due to the strain that the components imposed, blocks, that formed the mold, suffered some deformation. In the end, the quadrants of the frames and girders had small gaps, and did not fit well. So, for future construction of jigs, have to be mandatory made this by a solid and consistent material, such as wood.

Frames and girders construction was more complex than expected. Until apply the procedure considered more feasible, there were quite a few setbacks. Due to the bonding area between all the components was so small, it has become very difficult to do the correct bonding. The epoxy adhesive working time was too short, forcing a quick bonding work, reducing the quality. Many parts have to be peeled away and bonded again, abruptly increasing the construction time of the section. For this reason there was no time to finish the construction of all the girders. After all, the construction method proved to be feasible, but depends heavily on the experience and thoroughness of hand labor.

Finally, after all the parts were built, they were fitted in order to form the section. The locking system used, theoretically functional, has not been shown the appropriate after construction. The manufacture of these fittings was very complex because there could be no discrepancy between the pieces, and that is something almost impossible in a manual manufacturing. In final assembly, many components of the locking systems broke due to the efforts, and that did not fulfill the purpose.

The last point in this chapter was the conceptual design of an assembling tool. This design meets all the requirements demanded by the working group on this project. If the design of the structure needs to be changed, or transportation needs demand it, it is easy to adapt the concept of this tool to the new requirements.

5. Conclusion

5.1 Dissertation synthesis

The content of this dissertation includes two different works. The first was the adaptation of a blimp for stability and control tests. According to the result of these tests it was possible to proceed to the second objective. This included the study of gasbags materials and the testing of manufacturing techniques to apply on the structure and gasbags.

The blimp adaptation proved to be efficient, and allowed to do the necessary flight tests. After these tests, that validate some basic concepts of flight control, it was possible to proceed to the construction planning of the Prototype 3’s structure and gasbags.

Regarding the gasbags, it was decided to make a brief study about materials, looking for fabrics that met permeability and manufacture requirements. The information available was poor, such as access to suppliers. The fabrics that were possible to acquire had no information about permeability, and because of that, it was necessary to make some testes. As we did not have access to appropriate measurement tools, the solution passed through very simple permeability tests, that only gave us qualitative and not quantitative values. It was concluded that none of fabrics we had, was ideal for the final construction of Prototype 3’s gasbags. However, it was found that the material for the manufacturing of these component needs to be heat sealable, so it was possible to validate the manufacturing method of them.

Regarding the construction of the structure, as this is very complex, it was developed a nomenclature for the manufacturing organization. After that, we proceeded to the construction tests to determine the best manufacturing method. This was a very slow process because it was handmade, and there were several flaws. These flaws have been flagged, and finally, we can say that the procedures advised ensure optimization of time and quality of construction.

It was also design a conceptual assembling jig for the final structure assembly. This tool will allow to do a correct assembling, and also as transport support. This design can be easily adapted according to the specifications of the final project of Prototype 3.

5.2 Final considerations

This dissertation covered a lot of practical work and, to be well performed, need good conditions of space, tools and materials. Unfortunately, the available space was very small, and forced, for example, to divide the frames into four parts. Otherwise it would not be possible to build them. This need took more time than necessary for construction, and also increased the weak points, fittings, reducing the quality of the assembly and also the structure performance.

It is essential that Prototype 3 structure and gasbags' manufacture be carried out in a large space, with access to all the necessary tools and good ventilation. This place should also be, preferably, where flight tests will be held. It is also important that all manufacturing operators be properly trained.

The maximum quality of construction is guaranteed only if these requirements are met, if not, the quality of construction will decrease with the increasing lack of conditions.

Another problem that delayed the dissertation practical work, was the lack of interest of companies to provide material for gasbags. Some did not respond, others did not supply for Portugal and others did not show interest in providing information. This made it impossible to research the appropriate material for gasbags.

In general, it is concluded that the main objectives were achieved and this dissertation was an important part of *Urblog Project*, allowing its continuance.

5.3 Prospects for future work

Due to the current work and acquired knowledge and experience it is believed that the next steps in this work should cross the following investigation lines:

- Find gasbags materials that meet the main objectives of permeability and construction;
- Develop a gas inlet and retention system for gasbags;
- Adapt the assembling jig according to possible changes in the structural design;
- Design a coupling mechanism to attach the gasbag into the structure.

References

[1] Khoury, G.A. and J.D. Gillett.: “Airship Technology”, 1 ed. Cambrige Aerospace, Series 10, 1999.

[2] “Airship and Blimp Resources”, http://www.myairship.com/faq/, [Last access on 10-08-2015].

[3] “Types of Airship”, http://www.airship-association.org/cms/node/28, [Last access on 10/08/2015].

[4] “Rigid Airships”, http://www.airship-association.org/cms/node/6, [Last access on 11-08-2015].

[5] “D'ORCY'S AIRSHIP MANUAL”, LADISLAS D'ORCY. 1917.

[6] “Hindenburg Design and Technology”, http://www.airships.net/, [Last access on 11-08-2015].

[7] Galbraith, D.: “Zeppelins under construction”, http://www.oobject.com/category/zeppelins-under-construction/, [Last access on 11-08-2015].

[8] “SkyKitten”, http://www.worldskycat.com/skycat/skykitten.html, [Last access on 15-08-2015].

[9] Machry, T.R.: “Dirigíveis: uma alternativa para o transporte de cargas especiais”, Master Thesis, 2005, Universidade Federal do Rio de Janeiro.

[10] Craveiro, M.: “Nortávia lança dirigível à escala real em 2016”, in Ver Portugal 2012.

[11] Rajan, V.N., Sivasubramanian, K., and Fernandez, J.: “Accessibility and ergonomic analysis of assembly product and jig designs”, International Journal of Industrial Ergonomics, 1997, Vol. 23, pp. 473-487.

[12] Ryerson University: “Design for Manufacturing: Jigs & Fixtures in Aircraft Industries”, lecture presentation, 2004.http://www.geocities.ws/sm_hashemi/AER814_2004_FV.pdf [Last access 16-08-2015].

[13] Handasyde, G.H.: “Jigs for Aircraft Construction: A Survey of Current Practice with some Suggestions for Improvement and Wider Application”. Aircraft Engineering and Aerospace Technology, 1932, Vol. 4, no. 6, pp. 143-145.

[14] Jigs, Special Tools http://www.moreggia.com/Aerospace/Main_Activities/Jigs/jigs.html [Last access on 15-08-2015].

[15] O'Connor, M.:“Airbus Trials Showing Strong Results” in RFID Journal 2018, pp 1-2. http://www.rfidjournal.com/articles/view?4036#back-from-modal, [Last access on 14-08-2015].

[16] “Flitzer Sport Flying Association”, http://www.flitzerbiplane.com/JohnMorris.shtml, [Last access on 16-08-2015]

[17] Liao, L. and Pasternak, I.: “A review of airship structural research and development”. Aerospace Science, 2009, Vol. 45, no. 4, pp 83 – 96.

[18] Litchfield, P.W. and Allen, H.: “WHY? Why has America no Rigid Airships?”, 1945, THE CORDAY & GROSS CO. http://scilib-avia.narod.ru/Airships/index.html [Last access on 21-08-2015]

[19] “Prussian Light Steam Zeppelin”, http://www.tlucretius.net/Sophie/Castle/SteamZep.html, [Last access on 19-08-2015].

[20] Ludwig, D., “Auxiliary device for assembling airships”, United States Patent, Patent number: 1651754 A, December 6, 1927.

[21] Schütze, R.: “Lightweight carbon fibre rods and truss structures”, Materials & Design, 1997, Vol. 18, pp 231-238.

[22] “Zeppelins under construction: Britain's R 101 airship under construction at the Royal Airship Works, Cardington”. http://www.oobject.com/zeppelins-under-construction/britain039s-r-101-airship-under-construction-at-the-royal-airship-works-cardington/8595/[Last access on 19-08-2015].

[23] Miller, T. and Mandel, M.: “Airship Envelopes: Requirements, Materials and Test Methods”, pp 1-12.

[24] Broen Intelligent Flow Solutions, “Small Molecule Gases”, Technical White Paper, http://www.broen.us/en/LAB-and-ESS.aspx, [Last access on 20-08-2015].

[25] Wood-Adams, P.: “GCH 6101- Polymer – Diffusion”, Lecture notes of Physical Chemistry of Polymers, Concordia-Faculty of Engineering & Computer Science.

[26] Tremblay, P., et al.: “Gas permeability, diffusivity and solubility of nitrogen, helium, methane, carbon dioxide and formaldehyde in dense polymeric membranes using a new on-line permeation apparatus”, Journal of Membrane Science, 2006, Vol. 282, pp. 245-256.

[27] Sherwood, A.: “Making Mylar Envelopes”, in RCgroups, May 2005. http://www.rcgroups.com/forums/showthread.php?t=489372, [Last access 15-08-2015].

[28] “7 Steps to a Better Bond-Line”, October 4, 2007. http://www.designworldonline.com/7-steps-to-a-better-bond-line, [Last access on 10-9-2015].

[29] Motiwala, N.I., et al.: “Conceptual Approach for Design, Fabrication and Testing of Indoor Remotely Controlled Airship”, Advanced Materials Research, 2013, Vol. 690-693, pp. 3390-3395.

[30] González, D.N.: “STABILITY AND CONTROL OF HYBRID AIRSHIPS: A NEW CONCEPT”, Aeronautical Engineering MSc Thesis, Covilhã, Universidade da Beira Interior, 2015.

[31] Carbon Mods: “Carbon Fibre Laminating Starter Kit Guide”, http://www.carbonmods.co.uk/Downloads/Carbon-Mods-Carbon-Fibre-Lamination-Starter-Kit-Guide.pdf, [Last access on 28-08-2015].

[32] “Covering Film Solid White (5mtr) 113 (EU Warehouse)”, http://www.hobbyking.com/hobbyking/store/__43172__Covering_Film_Solid_White_5mtr_113_EU_Warehouse_.html, [Last access on13-09-2015].

[33] "Turnigy Covering Film Iron", http://www.hobbyking.com/hobbyking/store/__8507__Turnigy_Covering_Film_Iron_.html, [Last access on 13-09-2015].

[34] Rose, S., et al.: "Super Airships, in Rise of the Machines", 2014, Discovery Canada.

[35] "Archimedes Principle Formula", http://formulas.tutorvista.com/physics/archimedes-principle-formula.html, [Last access on 07-09-2015].

[36] "Fluid Properties Calculator", http://www.mhtl.uwaterloo.ca/old/onlinetools/airprop/airprop.html, [Last access on 30-09-2015].

[37] Aero Drum Lta: "3 & 3,5 m INDOOR RC BLIMP - Specification", March 2014.

[38] Gamboa, P.: "Fabricação e Manutenção de Aeronaves-Fabricação em Madeira", Lecture presentation, Universidade da Beira Interior, 2013.

[39] "ET515 Semi Flexible 15min Epoxy Adhesive 50ml Twin Tube", http://www.easycomposites.co.uk/products/structural-adhesives/semi-flexible-15min-epoxy-adhesive.aspx, [Last access on 15-09-2015].

[40] "50ml Twin Tube Cartridge Gun Dispense", http://www.easycomposites.co.uk/products/structural-adhesives/50ml-twin-tube-cartridge-gun-dispenser.aspx, [Last access on 15-09-2015].

[41] "Static Mixer Nozzles for 50ml Twin Tube", http://www.easycomposites.co.uk/products/structural-adhesives/static-mixer-nozzle-50ml.aspx, [Last access on 15-09-2015].

[42] "Carbon Fibre Strip 1mm x 6mm - 2m Length [OS2]", http://www.easycomposites.co.uk/products/carbon-fibre-strip/1mm-x-6mm-carbon-fibre-flat-bar-strip-2m.aspx , [Last access on 15-09-2015].

[43] "Mirka P120 Waterproof Wet and Dry Abrasive Sanding Paper 10 Sheets" http://www.easycomposites.co.uk/products/mirka-abrasives/p120-waterproof-wet-and-dry-paper.aspx, [Last access on 15-09-2015].

[44] "Pultruded Carbon Fibre Square Box Section 6mm (4mm)", http://www.easycomposites.co.uk/products/carbon-fiber-section/carbon-fibre-box-section-6mm-4mm.aspx, [Last access on 15-09-2015].

[45] "Perma-Grit Sanding Block Small" , http://www.easycomposites.co.uk/products/perma-grit/small-sanding-block.aspx, [Last access on 15-09-2015].

ANNEX 1

Permeability Tests Results

Permeability tests results

1. Permeability test of *Metalized Polyester film* fabric

- Test duration - 72 hours
- Material weight – $2{,}28 * 10^{-2}$ kg

	Mass lifted by helium (Kg)	Volume of Helium (m^3)	Percentage of Helium Lost (%)
Balloon filled with helium (t_0)	$4{,}99 * 10^{-2}$	$4{,}72 * 10^{-2}$	63,3
Balloon filled with helium (t_{72})	$1{,}83 * 10^{-2}$	$1{,}73 * 10^{-2}$	

2. Permeability test of *ORACOVER® AIR MEDIUM* fabric results

- Test duration - 72 hours
- Material weight – $3{,}90 * 10^{-2}$ kg

	Mass lifted by helium (Kg)	Volume of Helium (m3)	Percentage of Helium lost (%)
Balloon filled with helium (t_0)	$4{,}44 * 10^{-2}$	$4{,}20 * 10^{-2}$	83,78
Balloon filled with helium (t_{72})	$7{,}20 * 10^{-3}$	$6{,}82 * 10^{-3}$	

ANNEX 2

Scientific Paper Accepted for Publication at the 18th ATRS Conference

18TH ATRS WORLD CONFERENCE

AIRSHIPS AND AEROSTATS TECHNOLOGY. A STATE OF ART REVIEW

António Marques, Pedro Reis, Tânia Amaral, Sara Claro,
Tiago Santos, João Neves, Jorge Silva
LAETA/UBI-AeroG, Aerospace Sciences Department, Faculty of Engineering
University of Beira Interior, Covilhã, Portugal
Tel: +351 275 329 732; Fax: +351 275 329 768
jmiguel@ubi.pt

ABSTRACT

Nowadays new airships or Light than Air (LTA) aircrafts and aerostats are being tested and used for military and civilian purposes all over the world. This revived interest about airships and aerostats brings a multitude of new technical concepts resulting from a deep interdisciplinary research so that the actual state of art about them paves the way for renewed horizons regarding its use and operation in the next future.

With those technological improvements it is expected that airships will become soon a competitive mean of transport for linkage mainly with areas only served by weak or degraded transport infrastructures. Regarding the principles of sustainable development of air transport, airships are also the most environmentally friendly vehicles with lower fuel consumption and higher endurance. Therefore they are conquering new still unexplored markets.

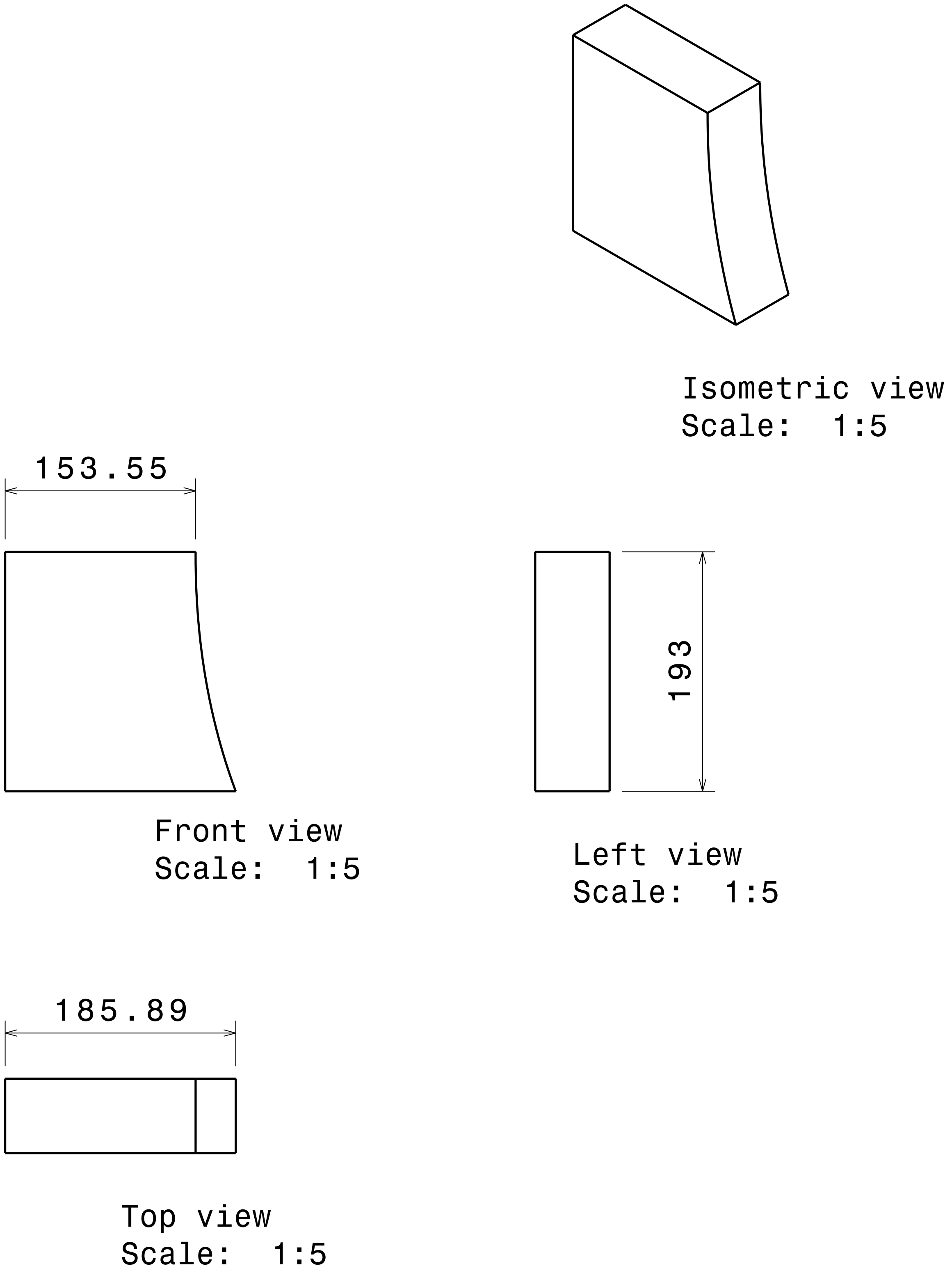
This work aims to present a state of art review about history and use of airships and aerostats, and to evidence how technological improvements in the recent past may impact positively its performance and thus its use in different scenarios in future.

KEYWORDS: Airships and aerostats, Technological improvements, Air transport sustainability

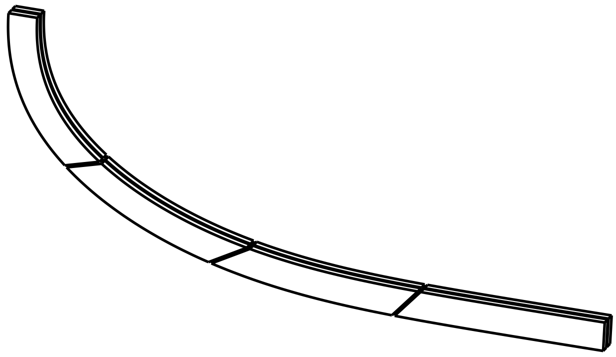
CLASSIFICATION: Aviation and Economics Development, Aviation Case Study, Inter-Modal and Air Travel Alternatives

ANNEX 3

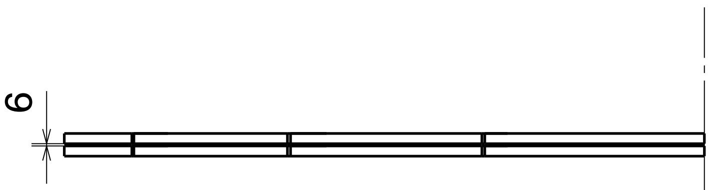
Technical draws of the assembling jig



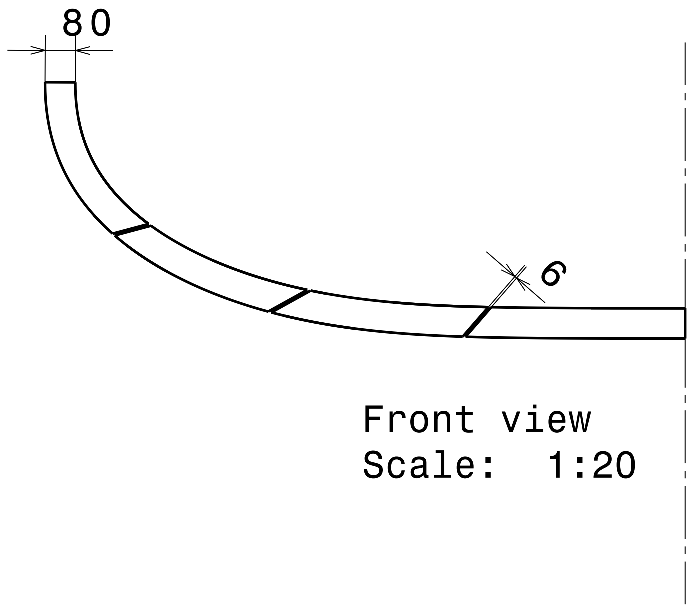
DESIGNED BY: Sara DATE: 24-09-2015		Nome	Peça de encaixe 1 Caverna 3-lado esquerdo	I _ H _
CHECKED BY: XXX DATE: XXX		Material	Poliestireno Extrudido	G _
		Unidades	mm	F _
SIZE A4				E _ D _
SCALE 1:1	WEIGHT (kg) XXX			C _ B _ A _



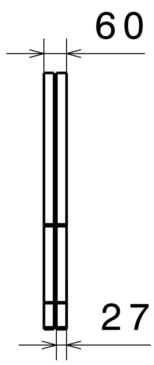
Isometric view
Scale: 1:20



Bottom view
Scale: 1:20

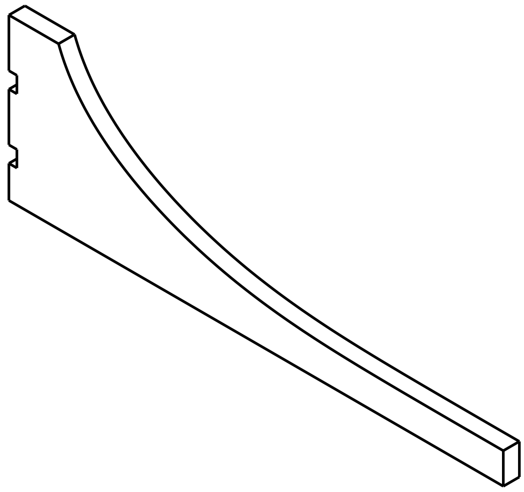


Front view
Scale: 1:20

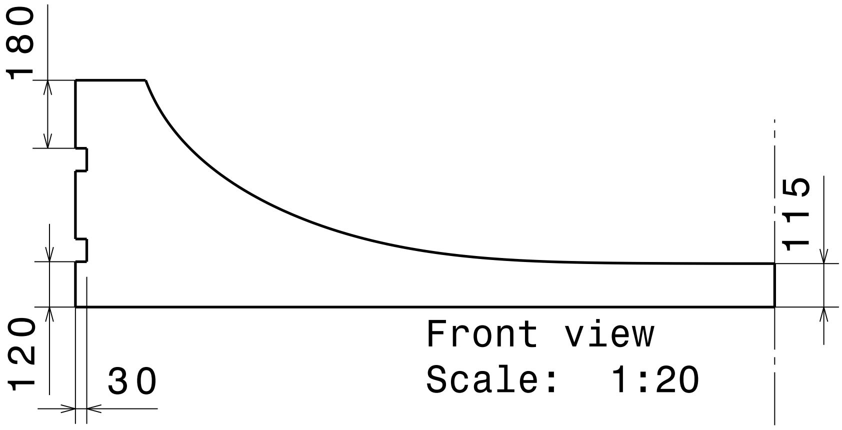


Left view
Scale: 1:20

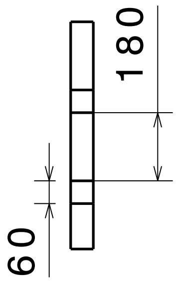
DESIGNED BY: Sara DATE: 24-09-2015	Name	Peça de encaixe 2 Caverna 3 - Lado Esquerdo	I	_
			H	_
CHECKED BY: XXX DATE: XXX			G	_
	Material	Poliestireno Extrudido	F	_
SIZE A4			E	_
	Unidades	mm	D	_
SCALE 1:1	Comments	XXXX	C	_
			B	_
			A	_



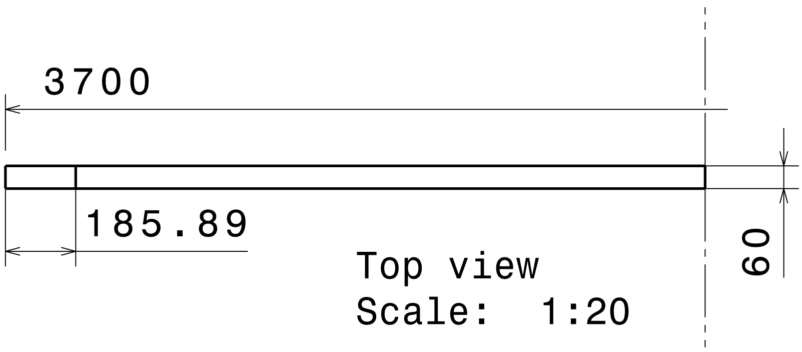
Isometric view
Scale: 1:20



Front view
Scale: 1:20

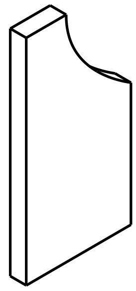


Left view
Scale: 1:20

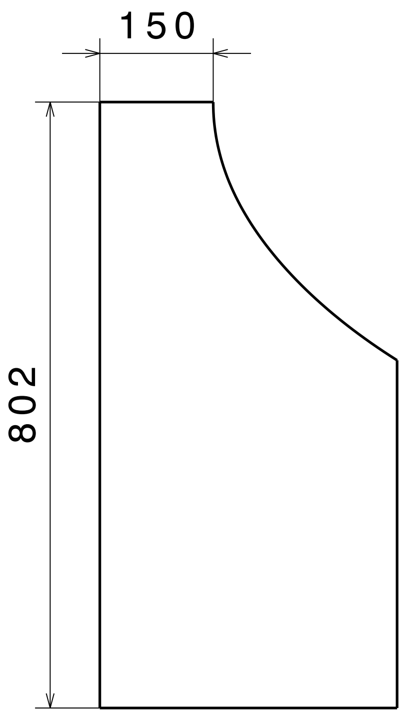


Top view
Scale: 1:20

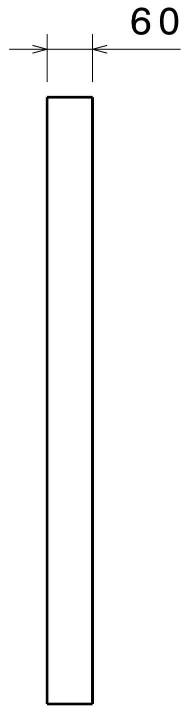
DESIGNED BY: Sara DATE: 24-09-2015	Name	Peça principal Caverna 3-lado esquerdo	I	_
CHECKED BY: XXX			H	_
	Material	Poliestireno extrudido	G	_
DATE: XXX			F	_
	Unidades	mm	E	_
SIZE A4			D	_
SCALE 1:1	WEIGHT (kg)		C	_
			B	_
			A	_



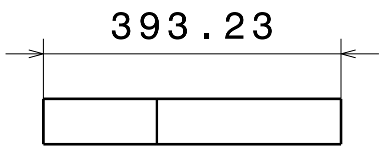
Isometric view
Scale: 1:20



Front view
Scale: 1:10

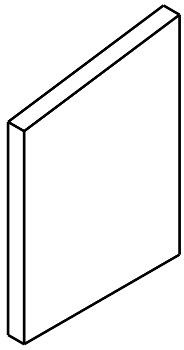


Left view
Scale: 1:10

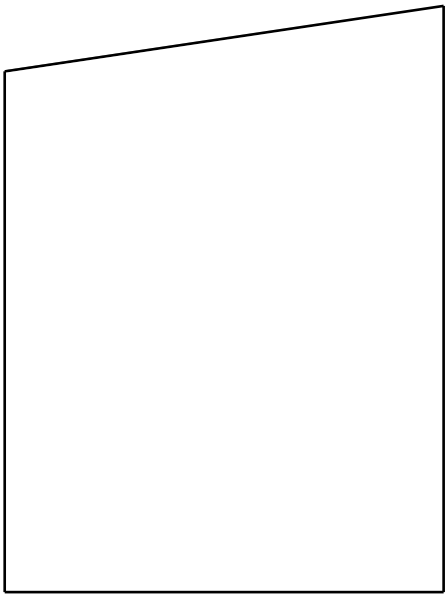


Top view
Scale: 1:10

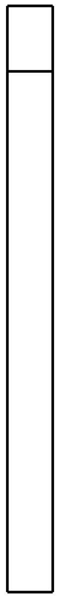
DESIGNED BY: Sara DATE: 24-09-2015	Nome	Peça de suporte frente	I	_
			H	_
CHECKED BY: XXX DATE: XXX	Material	Poliestireno Extrudido	G	_
	Unidades	mm	F	_
SIZE A4			E	_
			D	_
SCALE 1:1 / WEIGHT (kg) XXX			C	_
			B	_
			A	_



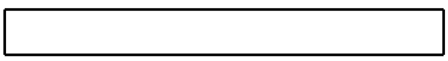
Isometric view
Scale: 1:20



Front view
Scale: 1:10



Left view
Scale: 1:10



Top view
Scale: 1:10

DESIGNED BY: Sara DATE: 24-09-2015	Nome	Peça de suporte trás	I	_
			H	_
CHECKED BY: XXX DATE: XXX	Material	Poliestireno Extrudido	G	_
	Unidades	mm	F	_
SIZE A4			E	_
			D	_
SCALE 1:1 / WEIGHT (kg) XXX			C	_
			B	_
			A	_